ESSAYS IN INCENTIVE AND INFORMATION ECONOMICS

By

CHIFENG DAI

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2003

ACKNOWLEDGMENTS

I am especially grateful to the chairman of my dissertation committee, David Sappington, for his patient guidance, helpful suggestions and insightful comments. I thank Chunrong Ai, Joel Demski, Jonathan Hamilton, Tracy Lewis, and Steven Slutsky for their valuable suggestions and comments on my research. Financial support from a Walter-Lanzillotti research grant is also gratefully acknowledged.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS ii

CHAPTERS

1 INTORDUCTION 1

2 OPTIMAL CONTRACTING WITH WEALTH-CONSTRAINED OPERATORS OF UNKOWN ABILITY 5

2.1 Introduction 5
2.2 Elements of the Model 7
2.3 Properties of the Optimal Contract 9
  2.3.1 Benchmark Solution 9
  2.3.2 The Optimal Contract 12
2.4 Conclusion 20
2.5 Notes 21

3 THE APPEALS PROCESS IN INCENTIVE PROBLEMS 23

3.1 Introduction 23
3.2 The Model 27
3.3 The Optimal Contract with Perfect Evaluation 29
3.4 The Optimal Contract with Imperfect Evaluation 30
3.5 The Appeals Process 35
  3.5.1 Costless Appeals Process 40
  3.5.2 Costly Appeals Process 42
3.6 Conclusion 50
3.7 Notes 51

4 SELECTING COST DISTRIBUTIONS 53

4.1 Introduction 53
4.2 The Model 55
  4.2.1 Description of Buyer and Seller 55
  4.2.2 Contracting for Supply 58
  4.2.3 Timing of the Model 58
4.3 Seller's Preferences for Distribution 59
4.4 Optimal Contracts 62

4.5 Buyer's Preferences for Contracting with Sellers 69
  4.5.1 Buyer's Preferences for Distribution 69
  4.5.2 Buyer's Preference for Ex Ante Knowledge of Seller 71
4.6 Conclusion 74
4.7 Notes 75

5 CONCLUSION 76

APPENDICES

PROOF OF PROPOSITIONS IN CHAPTER 2 81

PROOF OF PROPOSITIONS IN CHAPTER 3 91

PROOF OF PROPOSITIONS IN CHAPTER 4 105

LIST OF REFERENCES 110

BIOGRAPHICAL SKETCH 114

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

ESSAYS IN INCENTIVE AND INFORMATION ECONOMICS

By

Chifeng Dai

August 2003

Chair: David Sappington
Major Department: Economics

My dissertation studies issues in Information and Incentives Economics. Chapter 1 examines how a project owner optimally selects a project operator and motivates him to deliver unobservable effort when potential operators are wealth-constrained. I show that either a pooling or a separating contract can arise in equilibrium. In a separating contract, the more capable potential operator is either selected more often but awarded a smaller share of profit; or selected less often but awarded a larger share of profit.

The appeals process is used in many organizations (including administrative agencies, sports organizations, regulatory authorities, companies, etc.). Chapter 2 examines the effect of the appeals process on incentive contracts in the presence of imperfect performance evaluation and limited liability. Some surprising results emerge. For example, appeals may be denied even if the appeals process is quite accurate and costless. Furthermore, the appellant bears all the cost of any appeals. Also, an agent may be paid more initially for minimum performance than for superior performance. Under certain conditions, an increased accuracy of initial observation may reduce welfare. Welfare can also increase as the cost of the appeals process increases.

Chapter 3 analyzes how a buyer optimally contracts with a seller who is privately informed about his likely costs. Eventually the seller may learn more about his actual cost after signing the contract. I demonstrate that sellers prefer riskier cost distributions. Optimal contracts offer sellers with riskier cost distributions greater discretion in choosing output levels, whereas production choices are more restricted for sellers with more certain cost distributions intended to extract rents from riskier sellers. The buyer also prefers contracting with sellers with riskier cost distributions. However, in some settings, the buyer prefers sellers to be uninformed about their cost distributions.

CHAPTER 1
INTRODUCTION

Optimal contracts in the presence of moral hazard and adverse selection have received considerable attention in the literature. However, most studies ignore wealth constraints. In practice, economic parties often are wealth-constrained. For example, CEOs in large corporations usually have little wealth relative to the assets they control. Entrepreneurs typically lack the funds required to develop and market their own inventions; and so seek the financial support of venture capitalists. Therefore, it is important to examine optimal contracts in the presence of wealth constraints. Chapter 2 examines how a project owner optimally selects a project operator and motivates him to deliver unobservable effort when potential operators have limited wealth and private knowledge of their ability.

I demonstrate that wealth constraints influence optimal contracts in two fundamental ways. First, wealth constraints prevent the project owner from receiving the full value of the project. Furthermore, profit sharing results in equilibrium, which diminishes the effort supplied by the operator. Second, wealth constraints can prevent a high-ability potential operator from outbidding his low-ability counterpart. As a result, the project sometimes is assigned to an operator of lower ability. Together, these two effects imply that wealth constraints give rise to diluted incentives and ex post allocation inefficiency in the equilibrium. Further, I show that when the abilities of potential operators are common knowledge, the project owner always selects the more capable potential operator. However, the operator's share of realized profit can either increase or decrease with his ability, depending on the nature of his production technology. When potential operators are privately informed about their abilities, either a pooling or a separating contract can arise in equilibrium. The nature of the optimal contract varies with the elasticity of an operator's expected profit of operation with respect to the payment for success. In a separating contract, the more capable potential operator is either selected more often but awarded a smaller share of profit, or selected less often but awarded a larger share of profit.

Performance is often difficult to measure perfectly in practice. For example, the level of airport security, the financial health of a firm (e.g., Enron and WorldCom), the damage caused by hazardous wastes, and the impact of employees' misconduct are all difficult to measure. Consequently, incorrect judgments about the activities of economic actors may arise, and result in incorrect decisions. In the principal-agent literature, while most studies presume that the principal can observe the agent's performance perfectly, some studies show that the inability to observe performance perfectly is not constraining. For example, Picard (1987), Riordan and Sappington (1988), and Caillaud, Guesnerie and Rey (1992) show that the principal can achieve efficient outcomes and fully extract the rent of a risk-neutral agent as long as the principal can observe a signal correlated with the agent's private information. However, such a conclusion is not obtainable when the agent's liability is limited. Legal or institutional restrictions often prevent an employer from imposing a large penalty on employees. For example, Dickens, Katz, Lang and Summers (1989) said "An important aspect of American and English common law is the refusal of the courts to enforce contract provisions that are found to be 'penalties'. In particular, contract provisions calling for 'liquidated damages' for breach of contract that exceeds the loss caused by the breach are viewed as penalties and not enforced."

Chapter 3 examines the effect of the appeals process on optimal incentive contracts in the presence of imperfect performance evaluation and limited liability. Many organizations, such as administrative agencies, sports organizations, regulatory authorities, and companies, use an appeals process to allow an agent to challenge a principal's judgment. I study the following:

- Conditions under which it is optimal to implement an appeals process.
- The optimal allocation of the cost of an appeal between the employer and the appellant.
- Optimal rewards in an appeals process.
- The effect of the cost of the appeals process.
- The effect of the accuracy of initial observations and the appeals process.

In standard adverse-selection problems, suppliers typically are assumed to have perfect private information about their costs when contracting. In practice, though, a supplier often possesses only imperfect information when he signs a contract or makes a production decision. For instance, builders can only estimate the cost of materials when negotiating a construction contract. Similarly, health care providers know only the distribution of costs for treating a population of patients when contracting with health insurers. Chapter 4 studies how a buyer optimally arranges for the exchange of goods with a seller who is privately informed about his cost distribution instead of his actual cost at the time of contracting. This adverse selection problem raises new and interesting questions: First, what is the seller's preference regarding different cost distributions? Second, are the preferences of the buyer and the seller regarding different cost distributions aligned or in conflict? Third, does the buyer prefer contracting with an informed seller or with a seller uninformed about his cost distributions?

I examine these issues and the properties of optimal contracts in two different environments. The environments differ primarily in the nature of the seller's information when he signs the contract and when he makes production decisions. In the first environment, costs are revealed sequentially to the seller. At the time of contracting, the seller is privately informed about his cost distribution. Eventually, just before production, the seller observes a perfect signal that reveals his exact cost. In the second environment, the seller cannot observe his exact cost before production. However, he obtains an imperfect signal of his cost before production. At the time of contracting, the seller is privately informed about the distribution of the signal. In both settings, the buyer is unable to observe either the cost (signal) distribution or the realization of the eventual signal the seller receives.

CHAPTER 2
OPTIMAL CONTRACTING WITH WEALTH-CONSTRAINED OPERATORS OF UNKOWN ABILITY

2.1 Introduction

Optimal contracts in the presence of moral hazard and adverse selection have received considerable attention in the literature. However, most studies ignore wealth constraints. In practice, economic parties often are wealth-constrained. For example, CEOs in large corporations usually have little wealth relative to the assets they control. Entrepreneurs typically lack the funds required to develop and market their own inventions, and so seek the financial support of venture capitalists. Therefore, it is important to examine optimal contracts in the presence of wealth constraints.

We examine how a project owner optimally selects a project operator and motivates him to deliver unobservable effort. Potential operators have limited wealth and private knowledge of their ability. We demonstrate that wealth constraints influence optimal contracts in two fundamental ways. First, wealth constraints prevent the project owner from receiving the full value of the project. Furthermore, profit sharing results in the equilibrium, which diminishes the effort supplied by the operator. Second, wealth constraints can prevent a high-ability potential operator from outbidding his low-ability counterpart. As a result, the project sometimes is assigned to an operator of lower ability. Together, these two effects imply that wealth constraints give rise to diluted incentives and ex post allocation inefficiency in the equilibrium.

We also show that when the abilities of potential operators are common knowledge, the project owner always selects the more capable potential operator. However, the operator's share of realized profit can either increase or decrease with his ability, depending on the nature of his production technology. This is because shares of the realized profit constitute the only source of compensation for both the project owner and the project operator when potential operators have no initial wealth. Under some production technologies, the project owner finds it optimal to award a more capable operator a larger share of profit because doing so induces a larger increase in the probability of success and therefore a larger increase in expected total surplus. However, under some other technologies, the project owner finds it optimal to award a more capable operator a smaller share of profit because doing so does not reduce the operator's effort substantially; and it also secures a larger share of realized profit for the owner.

The project owner would always prefer to select a more capable operator for the project if she could observe potential operators' abilities. When potential operators are privately informed about their abilities, the only way the project owner can do so without inducing the low-ability operator to exaggerate his ability is to couple a higher probability of operation with a smaller share of profit. However, a smaller share of profit reduces a more capable operator's incentive to deliver effort. Under some production technologies, the project owner finds it is optimal to select a more capable operator more often but award him a smaller share of profit. Under other technologies, the effort reduction of a more capable operator resulting from a smaller share of profit becomes so large that the project owner finds a pooling contract optimal; or even selects a more capable operator less often but awards him a larger share of profit (to ensure substantial effort supply). Consequently, when potential operators are privately informed about their abilities, either a pooling or a separating contract can arise in equilibrium. The nature of the optimal contract varies with the elasticity of an operator's expected profit of operation with respect to the payment for success. In a separating contract, the more capable potential operator is either selected more often but awarded a smaller share of profit; or selected less often but awarded a larger share of profit.

This analysis extends the work of Lewis and Sappington (LS) (2000b) who analyze a special case of the model considered here. LS adopt a functional form in which the key elasticity does not vary with the operator's ability. Consequently, for the reasons explained below, a separating equilibrium is optimal in the setting analyzed by LS and the more capable operator is always selected more often but awarded a smaller share of profit. More generally, pooling contracts and other separating contracts can be optimal as demonstrated below. We characterize the optimal separating and pooling contracts for a broad class of production functions. Our findings are important given that wealth constraints render both pooling contracts and separating contracts in many relevant practical settings.

We develop and explain these findings as follows. Section 2.2 describes the central elements of our model. Section 2.3 examines the general properties of an optimal contract. Section 2.4 summarizes the results and concludes with future research directions. The proofs of all formal results are provided in the appendix.

2.2 Elements of the Model

The owner of a project seeks to select an operator and motivate him to operate the project. The project will either succeed and provide a gross return $V > 0$; or fail and provide zero gross return. The success or failure of the project is observed publicly. The probability that the project succeeds is $p(\theta, e)$ for $e \geq 0$, where θ represents the operator's ability and *e* represents the effort that the operator delivers. The operator's effort is not observable to the project owner. Effort is necessary for success so that $p(\theta, 0) = 0$. We assume that higher effort and ability increase the probability of success at a decreasing rate so that $p_{\theta}(\theta, e) > 0$, $p_{e}(\theta, e) > 0$, $p_{\theta\theta}(\theta, e) < 0$, $p_{ee}(\theta, e) < 0$. Higher ability is also assumed to increase the marginal impact of effort so that $p_{\theta e}(\theta, e) > 0$.

There are two potential operators in our model. Each potential operator's ability θ is the realization of an identical and independent random variable. The realization is θ_H with probability q and θ_L with probability $1 - q$, where $0 < \theta_L < \theta_H$. Only the potential operator is privately informed about his own ability from the outset. For simplicity, we assume that both potential operators have zero initial wealth and an opportunity wage of zero. Furthermore, we assume the potential operators have the same marginal cost of effort, which is constant and normalized to unity.

Let μ_{ij} denote the operation probability the owner assigns to a potential operator when he reports ability θ_i and his counterpart reports ability θ_j, for $i, j \in \{L, H\}$. Also let T_i denote the equilibrium payment the owner makes to the operator who reports ability θ_i when he is selected and the project succeeds. No transfer payment occurs between the owner and the operator when the project fails. Call $\{\mu_{ij}, T_i\}$ the allocation that a potential operator receives when he reports ability θ_i and his counterpart reports θ_j, for $i, j \in \{L, H\}$.[1]

The timing in the model is as follows:

- The project owner offers the contract to both potential operators.
- Each potential operator decides whether to accept the contract. No penalty is imposed on a potential operator who rejects the contract.
- If both potential operators decide to accept the contract, each of them reports his own ability to the project owner.[2]
- The owner selects the project operator according to the contract.
- At the end of the operation, the outcome of the project is observed, and payment is made as promised in the contract.

2.3 Properties of the Optimal Contract

2.3.1 Benchmark Solution

As a benchmark, we first examine the optimal contract when potential operators only have private information about their effort supply but not their abilities. An agent who operates the project chooses his effort level to maximize his profit, which is the difference between the expected payment from the owner and the cost of his effort. Therefore, when T is the payment for success, an operator with ability θ chooses an effort level such that

$$e(\theta, T) \equiv \underset{e}{\operatorname{argmax}} \{p(\theta, e)T - e\} \tag{2-1}$$

The equilibrium expected profit for a potential operator with ability θ_H is

$$\pi(\theta_H, T) = p(\theta_H, e(\theta_H, T))T - e(\theta_H, T). \tag{2-2}$$

The corresponding equilibrium expected profit for a potential operator with ability θ_L is

$$\pi(\theta_L, T) = p(\theta_L, e(\theta_L, T))T - e(\theta_L, T). \tag{2-3}$$

For each type of operator, the project owner wants to maximize her net expected return, which is the difference between the expected gross return from the project and the expected payment to the operator. Therefore, for each type of operator, the project owner's problem is

$$\underset{T_i}{Max}\, W = p(\theta_i, e(\theta_i, T_i))[V - T_i]$$

Subject to

$$\pi(\theta_i) = p(\theta_i, e(\theta_i, T_i))T_i - e(\theta_i, T_i) \geq 0\,, \tag{2-4}$$

$$T_i \geq 0\,, \text{ where } i \in \{L, H\}. \tag{2-5}$$

Constraint 2-4 is the individual rationality constraint that guarantees the participation of both types of potential operators. Constraint 2-5 ensures the transfer payments to be nonnegative, which reflects the fact that both potential operators have zero initial wealth.

We present the properties of the optimal contract in this context in Proposition 1.

Proposition 1. Suppose that each potential operator's ability is common knowledge. Then, in the optimal contract

a The project owner always shares the realized profit with the operator.

b The optimal payment to the operator for success can either increase or decrease with the operator's ability conditional on his production technology.

c The project owner's expected surplus increases as the selected operator's ability increases.

If the potential operators were not wealth-constrained, the project owner could sell the project to the high-ability potential operator for its maximum expected value, $p(\theta, e^*(\theta))V - e^*(\theta)$, where $e^*(\theta) \equiv \underset{e}{\text{argmax}}\{p(\theta, e)V - e\}$. Then the selected operator would choose to deliver the socially optimal effort $e^*(\theta)$ and he would earn zero expected profit. When both potential operators have zero initial wealth, the project owner's only source of compensation is her share in the project. However, the share in the project is also the only source of incentive for the operator. Therefore, as Property a reports, the project owner has to promise to share the realized profit with the operator in order to motivate the operator; and the selected operator delivers less than the socially optimal level of effort $e^{*}(\theta)$.

Furthermore, when the share of the project is the only source of compensation for both the project operator and the project owner, the project owner uses the superior productivity of high-ability operator in an interesting manner. The high-ability operator has a relatively high marginal probability of success at any given level of effort. Thus, the project owner may prefer awarding a larger share of profit to a high-ability operator, because it can lead to a larger increase in the probability of success and therefore a larger increase in total surplus. On the other hand, the project owner may prefer awarding a smaller share of profit to a high-ability operator, because doing so may not reduce the operator's effort substantially; and it increases the share of realized profit that the owner keeps. Property b of Proposition 1 shows that, in an optimal contract, the operator's share of profit can either increase or decrease with his ability, depending on the production technology. In other words, under some technologies, the operator's ability and the share of profit he receives act as substitutes from the perspective of the owner. Under other technologies, they can act as complements.

For example, when the operator's probability of success is $p(\theta,e)=\alpha e^{\theta}$, the optimal share of profit for the operator is θ, which increases with θ. On the other hand, when the operator's probability of success is $p(\theta,e)=\theta\, e^{\gamma}$ as in LS, the optimal share of profit for the operator is γ, which does not vary with θ. To further study how the operator's share of profit varies with his ability in an optimal contract, we define Condition 1 as follows.

Condition 1: $p_{eee}(\theta, e) \le 0$ and $p_{ee\theta}(\theta, e) \le 0$.

Proposition 2 provides conditions under which the owner will optimally award the high-ability operator a smaller share of profit.

Proposition 2: Suppose that Condition 1 holds. Then when the abilities of operators are observed publicly, the principal will optimally award a larger share of profit to the low-ability operator.

Property c of Proposition 1 indicates that the project owner's expected surplus increases as the operator's ability increases. Therefore, the project owner will always award the project to the potential operator with the highest ability when she can observe each potential operator's ability.

2.3.2 The Optimal Contract

The results from the benchmark problem illustrate the effect of wealth constraints on the optimal contract when there is no adverse selection problem. However, in reality, a project owner often does not have perfect knowledge of the abilities of potential operators. For example, venture capitalists seldom have perfect information about entrepreneurs' abilities; and company owners often are not able to assess perfectly the qualifications of potential managers. Therefore, it is important to investigate the properties of an optimal contract when potential operators are privately informed about their abilities.

In this case, the equilibrium expected profit for a potential operator is the product of his expected profit from operation and his probability of operation. The equilibrium expected profit for a potential operator with ability θ_H is

$$\Pi(\theta_H, T_H) = \left[p(\theta_H, e(\theta_H, T_H))T_H - e(\theta_H, T_H)\right]\left[q\mu_{HH} + (1-q)\mu_{HL}\right]. \tag{2-6}$$

The corresponding equilibrium expected profit for a potential operator with ability θ_L is

$$\Pi(\theta_L, T_L) = \left[p(\theta_L, e(\theta_L, T_L))T_L - e(\theta_L, T_L)\right]\left[(1-q)\mu_{LL} + q\mu_{LH}\right]. \tag{2-7}$$

The project owner wants to maximize her net expected return, which is the difference between the expected gross return from the project and the expected payment to the operator. Therefore, the project owner's problem is

$$\begin{aligned} \underset{T,\mu}{Max}\ \Pi^P = {} & [p(\theta_H, e(\theta_H, T_H))(V - T_H)][2q^2\mu_{HH} + 2q(1-q)\mu_{HL}] \\ & + [p(\theta_L, e(\theta_L, T_L))(V - T_L)][2(1-q)^2\mu_{LL} + 2q(1-q)\mu_{LH}] \end{aligned}$$

subject to

$$\Pi(\theta_H) \geq 0; \tag{2-8}$$

$$\Pi(\theta_L) \geq 0; \tag{2-9}$$

$$\Pi(\theta_H) \geq \left[p(\theta_H, e(\theta_H, T_L))T_L - e(\theta_H, T_L)\right]\left[q\mu_{LH} + (1-q)\mu_{LL}\right]; \tag{2-10}$$

$$\Pi(\theta_L) \geq \left[p(\theta_L, e(\theta_L, T_H))T_H - e(\theta_L, T_H)\right]\left[q\mu_{HH} + (1-q)\mu_{HL}\right]; \tag{2-11}$$

$$T_H, T_L \geq 0 \tag{2-12}$$

$$\mu_{HL} + \mu_{LH} \leq 1; \tag{2-13}$$

$$\mu_{HH} \leq 1/2; \tag{2-14}$$

$$\mu_{LL} \leq 1/2; \tag{2-15}$$

$$\mu_{HH}, \mu_{HL}, \mu_{LH}, \mu_{LL} \geq 0. \tag{2-16}$$

The first term in the owner's objective function is the owner's expected return when the operator has ability θ_H times the probability that the selected operator has ability θ_H. The second term is the owner's expected return when the operator has ability θ_L times the probability that the selected operator has ability θ_L. Therefore, the sum of these two terms equals the owner's expected net return from the project. Constraints 2-8 and 2-9 are the individual rationality constraints that guarantee the participation of both types of potential operators. Constraints 2-10 and 2-11 are the incentive compatibility constraints that ensure both types of potential operators truthfully report their abilities. Constraint 2-12 ensures the transfer payments to be nonnegative. Constraints 2-13, 2-14, 2-15 and 2-16 bound the operation probabilities between 0 and 1.

When the project owner cannot observe the abilities of the potential operators, she must consider both how to select the desired operator and how to motivate the selected operator. The project owner could always assign the same contract to both potential operators and specify a particular share in the project and a particular probability of operation that does not vary with ability. However, as is evident in the benchmark problem, the project owner prefers to select a high-ability potential operator more frequently, because his greater productivity generates greater expected surplus for the project owner. However, the only way the project owner can do so without inducing the low-ability operator to exaggerate his ability is to couple a higher probability of operation with a smaller share of realized profit. Define T^* as the optimal payment for success for an operator when his ability, θ, is known to the project owner. Further, we define Condition 2 as follows.

Table 2-1. Optimal Solutions for various values of θ_H ,θ_L and q when V=2000, and α =0.001 ($p(\theta,e) = \alpha e^{\theta}$)

	θ_H	θ_L	q	T_H	T_L	μ_{HL}	μ_{LH}
1	0.80	0.80	0.70	1600.00	1600.00	0.50	0.50
2	0.80	0.75	0.70	1581.75	1581.75	0.50	0.50
3	0.80	0.70	0.70	1575.08	1575.08	0.50	0.50
4	0.80	0.65	0.70	1575.08	1575.08	0.50	0.50
5	0.80	0.60	0.70	1570.84	1570.84	0.50	0.50
6	0.80	0.55	0.70	1570.84	1570.84	0.50	0.50
7	0.80	0.50	0.70	1570.84	1570.84	0.50	0.50
8	0.80	0.45	0.70	1570.84	1570.84	0.50	0.50
9	0.80	0.40	0.70	1570.84	1570.84	0.50	0.50
10	0.80	0.35	0.70	1572.53	1290.00	0.34	0.66
11	0.80	0.30	0.70	1575.86	1063.25	0.19	0.81
12	0.80	0.25	0.70	1580.05	812.19	0.00	1.00
13	0.80	0.20	0.70	1575.77	774.84	0.00	1.00
14	0.80	0.15	0.70	1570.76	738.86	0.00	1.00
15	0.80	0.10	0.70	1564.64	704.04	0.00	1.00
16	0.70	0.70	0.35	1400.00	1400.00	0.50	0.50
17	0.70	0.65	0.35	1362.07	1326.02	0.46	0.54
18	0.70	0.60	0.35	1350.17	1238.77	0.40	0.60
19	0.70	0.55	0.35	1350.78	1139.89	0.32	0.68
20	0.70	0.50	0.35	1360.03	1032.46	0.25	0.75
21	0.70	0.45	0.35	1372.13	919.44	0.18	0.82
22	0.70	0.40	0.35	1385.71	803.53	0.12	0.88
23	0.70	0.35	0.35	1390.34	699.87	0.00	1.00
24	0.70	0.30	0.35	1393.24	599.95	0.00	1.00
25	0.70	0.25	0.35	1394.92	506.82	0.00	1.00
26	0.70	0.20	0.35	1316.33	447.04	0.00	1.00
27	0.70	0.15	0.35	1210.48	384.27	0.00	1.00
28	0.70	0.10	0.35	1032.22	306.29	0.00	1.00

Condition 2: $\frac{dT^*}{d\theta} \leq 0$.

When condition 2 holds, the owner prefers to award the high-ability operator a smaller share of profit if she can observe the operator's ability. In the presence of information asymmetry, the project owner prefers to offer two separate contracts:

- A relatively high probability of operation coupled with a relatively small share in the project, intended for a high-ability potential operator.
- A relatively low probability of operation coupled with a relatively large share in the project, intended for a low-ability potential operator.

However, when Condition 2 does not hold (i.e., the owner prefers to award the high-ability operator a larger share of profit), the above separating contract may not be optimal. This is because while selecting a high-ability operator more often can increase the project owner's expected surplus, reducing a high-ability operator's share of profit can reduce the project owner's expected surplus. When the latter effect dominates the former, the project owner may find that a pooling contract is optimal; or may even prefer to select a high-ability operator less often but award him a larger share of profit (to ensure substantial effort supply). Therefore, when Condition 2 does not hold, the project owner's preference regarding separating contracts is not clear.

For example, T^* does not vary with the operator's ability θ when the operator's success probability is $p(\theta, e) = \theta\, e^{\gamma}$. In this case, a high-ability operator is always selected more often but awarded a smaller share of profit.[4] On the other hand, T^* increases with the operator's ability θ when the operator's success probability is $p(\theta, e) = \alpha e^{\theta}$. Numerical examples in Table 2-1 shows that either a pooling contract or a separating contract can arise in equilibrium. Further, in a separating contract, a high-ability operator is selected less often but awarded a larger share of profit. We summarize these findings in Proposition 3.

Proposition 3. Suppose potential operators are privately informed about their abilities from the outset.

a Either a pooling contract or a separating can arise in equilibrium.

b The project owner always shares the realized profit with the operator; and the selected operator always earns positive expected profit.

c When condition 2 holds, the high-ability operator is always selected more often, but is awarded a smaller share of profit in a separating equilibrium.

d When condition 2 does not hold, the high-ability operator can be selected less often and awarded a larger share of profit in a separating equilibrium.

Given Proposition 2, Corollary 1 follows immediately from Proposition 3.

Corollary 1: When Condition 1 holds, in an optimal separating contract, the high-ability potential operator is always selected more often, but is awarded a smaller share of realized profit.

It remains to be determined when the project owner prefers a separating contract and when he prefers a pooling contract. To analyze this issue, define

$E_{\pi,\,T} \equiv \frac{d\pi(\theta,T)}{dT}\frac{T}{\pi(\theta,T)}$. In words, $E_{\pi,\,T}$ is the elasticity of a potential operator's expected profit of operating the project with respect to the payment for success.

Proposition 4. Suppose Condition 2 holds. Then

a A pooling contract is optimal when $E_{\pi,\,T}$ is strictly increasing in the operator's ability θ.

b A separating contract is optimal when $E_{\pi,\,T}$ is non-increasing in the operator's ability θ.

The intuition underlying Proposition 4 is as follows. When Condition 2 holds, the project owner prefers to select the high-ability operator more often but award him a smaller share of profit. However, when the elasticity of an operator's expected profit of operating the project with respect to his payment for success increases with his ability, a given percentage decrease in the payment for success induces a larger percentage reduction in expected profit when the operator has high-ability than when he has low ability. Consequently, a high-ability operator will be less willing to reduce his share of profit in exchange for a higher probability of operation. Therefore, given two separate contracts with the properties described in Property c of Proposition 3, a high-ability operator will prefer the option designed for the low-ability operator in which a relatively low probability of operation is coupled with a relatively large share of profit. On the other hand, a low-ability operator will prefer the option that couples a relatively high probability of operation with a relatively small share of profit. As a result, the project owner cannot implement any separating contracts with properties described in Property b of Proposition 3. In this case, a pooling contract is optimal. A pooling contact specifies the same share in the project and the same probability of operation (0.5) for all potential operators.

In contrast, when the aforementioned elasticity is nonincreasing in the operator's ability, a high-ability operator is at least as willing to as a low-ability operator is reduce his share of profit in exchange for a higher probability of operation. Therefore, a high-ability operator will weakly prefer a relatively high probability of operation coupled with a relatively small share of profit; and a low-ability operator will weakly prefer a relatively low probability of operation coupled with a relatively large share of profit. As a result, separating contracts as characterized in Property b of Proposition 3 can be implemented, and are optimal.[5] Corollary 2 follows immediately from Proposition 2 and Proposition 4.

Corollary 2: Under Condition 1,

a A pooling contract is optimal when $E_{\pi,\,T}$ is strictly increasing in the operator's ability θ.

b A separating contract is optimal when $E_{\pi,\,T}$ is non-increasing in the operator's ability θ.

Proposition 5 provides additional insight regarding the optimal contract when Condition 1 does not hold.

Proposition 5: Suppose Condition 1 does not hold. Then,

a A separating contract, where a high-ability operator is selected more often but awarded a smaller share of profit, is not optimal if $E_{\pi,\,T}$ is strictly increasing in the operator's ability θ.

b A separating contract, where a high-ability operator is selected less often but awarded a larger share of profit, is not optimal if $E_{\pi,\,T}$ is strictly decreasing in the operator's ability θ.

When the elasticity of an operator's expected profit of operating the project with respect to his payment for success is strictly increasing in his ability, a high–ability operator is less willing than a low-ability operator to reduce his share of profit in exchange for a higher probability of operation. Therefore, a separating contract, where a high-ability operator is selected more often but awarded a smaller share of profit, cannot be implemented. In contrast, when the elasticity is strictly decreasing in ability, a high-ability operator is more willing to reduce his share of profit in exchange for a higher probability of operation. In this case, a separating contract, where a high-ability operator is selected less often but awarded a larger share of profit, cannot be implemented.

It can be verified that $E_{\pi,T}$ increases with the operator's ability θ when the operator's success probability is $p(\theta, e) = \alpha e^{\theta}$. The numerical examples in Table 2-1 reveal that the high–ability operator is selected less often but awarded a larger share of profit in separating contracts in this case, consistent with Proposition 5.

2.4 Conclusion

We have examined how a project owner optimally selects a project operator and motivates him to deliver unobservable effort when potential operators are wealth-constrained. We have shown that wealth constraints have significant effects on the structure of optimal contracts. First, wealth constraints prevent the project owner from receiving the full value of the project and give rise to profit sharing in the equilibrium. Second, wealth constraints can prevent a high-ability potential operator from outbidding his low-ability counterpart. As a result, the project sometimes is assigned to potential operators of lower abilities. Consequently, diluted incentives and ex post allocation inefficiency arise in the equilibrium.

We have also shown that when the abilities of potential operators are common knowledge, the operator's share of profit can either increase or decrease with his ability, depending on the prevailing production technology. When potential operators are privately informed about their abilities, either a pooling or a separating contract can arise in the equilibrium. Which equilibrium arises depends upon the elasticity of operator's expected profit from the project with respect to the payment for success. Sufficient conditions for separating contracts to arise, and for pooling contracts to arise, were provided. In separating contracts, the more capable potential operator is either selected more often but awarded a smaller share of profit, or selected less often but awarded a larger share of profit.

Our model could be usefully extended in a variety of directions. First, it could be optimal for the project owner to conduct preliminary contests among potential operators in order to better discern their abilities. The optimal design of such contests and the conditions under which such contests are optimal would be interesting to explore. Second, repeated interaction between the project owner and potential operators could be considered. Past performance can reveal information about an operator's ability. It can also create wealth asymmetries among potential operators. How the project owner optimally constructs future assignments and sharing rules based upon potential operators' past performance and heterogeneous wealth merits investigation.

2.5 Notes

1. It is without loss of generality that the equilibrium payment is assumed a function of each potential operator's own report only. The reason is as follows. For any mechanism where each potential operator's payment does not depend only on his own report, there exists a corresponding payment scheme that provides potential operators the same expected profits but depends only on each potential operator's own report. Furthermore, since both project owner and potential operators are risk neutral and the production function is concave in effort, a deterministic payment scheme can render higher expected surplus to the project owner than a stochastic mechanism.

2. As shown in section III, both types of potential operators make positive expected profit from the optimal contract. Therefore, in the equilibrium, both potential operators will accept the optimal contract regardless of their abilities.

3. There are special classes of production functions for which pooling is always induced in equilibrium. For example, suppose $p(\theta,e)=p(X)$, where $X=X(\theta,e)$ and $X_e(\theta,e)=C$ (C is a scalar.). Then the first order condition of the operator's problem implies $p_X(X)X_e(\theta,e)T=p_X(X)CT=1$. Therefore, the X chosen by the operator does not depend on his ability level. In the presence of information asymmetry and wealth constraints, the project owner is indifferent between different types of potential operators because she is not able to extract additional rent from the

high-ability operator. A simple example of this class of production functions is $p(\theta, e) = 1 - \frac{1}{(\theta + e)^r}$.

4. See LS.

5. It can be verified that $E_{\pi, T}$ is constant in the operator's ability θ when the operator's success probability is $p(\theta, e) = \theta\, e^{\gamma}$ as in LS, which is consistent with Proposition 4.

CHAPTER 3
THE APPEALS PROCESS IN INCENTIVE PROBLEMS

3.1 Introduction

In practice, performance is often difficult to measure perfectly. For example, the level of airport security, the financial health of a firm (e.g., Enron and WorldCom), the damage caused by hazardous wastes, and the impact of employees' misconduct are all difficult to measure. Consequently, incorrect judgments about the activities of economic actors may arise, and result in incorrect decisions. For example, in the workplace, an employer might inadvertently penalize an industrious employee but reward an indolent employee as a result of evaluation errors. The appeals process is employed in many organizations such as administrative agencies, sports organizations, regulatory authorities, companies, etc. to allow an agent to appeal a principal's judgment. The objective of this paper is to examine the effect of the appeals process on optimal incentive contracts in the presence of imperfect performance evaluation and limited liability.

I consider a simple principal-agent relationship where a risk-neutral employer induces a risk-neutral employee to achieve certain level of performance. The employer requires at least a minimum performance from all employees, but prefers to induce a superior (and more costly) performance from a high-productivity employee. The minimum performance might be viewed as performing basic duties, such as arriving at work on time and performing routine daily assignments. The employer can easily discern if the employee performs these duties. The superior performance might entail superior creativity or efficiency that are more difficult to measure. The employer cannot observe the employee's productivity, and can only measure the employee's performance imperfectly. In contrast, the employee is privately informed about his own productivity and his effort at work, and can observe his performance perfectly. The employer's inability to measure the employee's performance perfectly would have no effect on her expected welfare if she is able to impose unlimited penalties on the employee when he is found to have delivered minimum performance.[1] However, legal or institutional restrictions often prevent an employer from imposing large penalty on employees. For example, Dickens, Katz, Lang and Summers (1989) said "An important aspect of American and English common law is the refusal of the courts to enforce contract provisions that are found to be 'penalties'. In particular, contract provisions calling for 'liquidated damages' for breach of contract that exceeds the loss caused by the breach are viewed as penalties and not enforced."

I examine the appeals process that allows the employee to lodge an appeal when an imperfect monitor suggests he has exaggerated his performance. I study

- Conditions under which it is optimal to implement an appeals process.
- The optimal allocation of the cost of an appeal between the employer and the appellant.
- Optimal rewards in an appeals process.
- The effect of the cost of the appeals process.
- The effect of the accuracy of initial observations and the appeals process.

I find that an optimal appeals process possesses several notable features. For example: first, the employer may deny all appeals even if the appeals process is quite accurate and costless; second, the appellant bears all the costs of the appeals process;

third, the employee may be paid more initially for minimum performance than for superior performance; fourth, the employer's welfare can increase as the cost of the appeals process increases; fifth, more accurate initial evaluations may reduce the employer's welfare.

These features are actually quite intuitive once the role of the appeals process in incentive contracts is understood. Imperfect performance evaluation restricts the employer's ability to reward an employee who has delivered superior performance and penalize an employee who has delivered minimum performance. Consequently, imperfect performance evaluation increases the employer's cost of motivating desired effort levels. The appeals process allows an employee to appeal when he is found to have delivered minimum performance, and therefore improves the employer's ability to reward an employee who has delivered superior performance. However, when the initial evaluation is sufficiently accurate, an employee is very likely to have delivered minimum performance when the initial evaluation reveals minimum performance. Allowing an employee to appeal in this situation is more likely to reward an employee who has delivered minimum performance and therefore reduces the employer's welfare. Consequently, the employer optimally denies any appeals in this situation.

When the appeals process is sufficiently accurate, the employer provides the greatest reward to an employee who is found to have delivered superior performance in the appeals process. Doing so best limits the rent the employee derives from evaluation errors. The employer delivers a positive payment when the employee is found to have delivered minimum performance in the initial stage in this setting. Doing so reduces the incentive of an employee who has delivered minimum performance to appeal.

Consequently, the employee may be paid more in the initial stage for minimum performance than for superior performance. As the initial evaluation becomes more accurate, an employee is more likely to have delivered minimum performance than superior performance when the initial evaluation reveals minimum performance. Therefore, increased accuracy provides more opportunity for an employee who has delivered minimum performance to appeal than for an employee who has delivered superior performance, and restricts the employer's ability to reward different performance levels differentially through the appeals process. As a result, the employer's welfare can decrease as the accuracy of the initial evaluation increases.

Institutional or legal restrictions on an employee's liability limit the ability of the employer to penalize employee who has delivered minimum performance. However, the cost of appealing can essentially act as a forfeitable bond that an employee must post in order to appeal. This forfeitable bond helps deter an employee who has delivered minimum performance from appealing. Therefore, it is optimal to impose all the costs of the appeals process on the appellant. When the employer is able to impose a large share of the cost of the appeals process on the appellant, her welfare can increase as the cost of the appeals process increases.

Shavell (1995) studies the role of the appeals process as a means of error correction in judicial settings where both parties can appeal. In contrast, I focus on the role that an appeals process can play in inducing superior performance in principal-agent settings where only the agent appeals. Daughety and Reinganum (2000) examine judicial decision making in a hierarchical judicial system, in particular, a trial court and an appeals court. In their model, a trial court aggregates credible evidence provided by the parties and comes to a judgment. The role of an appeals court is to use the defendant's choice about appeal to improve its estimate of the superior court's preferred interpretation of the law. In my model, both the initial evaluation and the appeals process serve to measure an employee's performance. Spitzer and Talley (2000) analyze a hierarchical system of judicial auditing where an appeals court is concerned with imprecision and ideological bias of a trial court. In contrast, there is no difference in ideology between the initial evaluation and the appeals process in my model.

I describe the central elements of the model in Section 3.2. As benchmarks, Section 3.3 presents the optimal contract with perfect observation, and Section 3.4 presents the optimal contract with imperfect observation. Section 3.5 examines the effect of the appeals process. Section 3.6 concludes the paper with future research directions. The proofs of all formal conclusions are in the Appendix.

3.2 The Model

A risk-neutral employer induces a risk-neutral employee to achieve certain level of performance Q. $e(\alpha,Q)$ denotes the level of effort required to achieve performance Q when the employee's productivity is α. More effort is required to produce higher quality, regardless of the employee's productivity, so $e_Q(\alpha, Q) > 0$. Futhermore, more effort is required to achieve a specified level of performance the lower is the employee's producitivty, so $e_\alpha(\alpha,Q) < 0$. The employee's productivity α is the realization of a binary random variable. High productivity, α_H, is realized with probability μ_H, while low productivity, α_L, is realized with probability μ_L, where $0 < \alpha_L < \alpha_H$ and $\mu_H + \mu_L = 1$. The employee is privately informed about his productivity α and effort *e*.

The employee's marginal cost of effort is assumed to be constant and is normalized to unity, regardless of his productivity. The employee's opportunity wage is zero.

There is an exogenous, minimum performance level Q_L that the employer requires of all employees. The employer prefers a higher performance level Q_H from the high-productivity employees, but not the low-productivity employees, because the extra benefit the employer derives from the increased performance exceeds the incremental cost of the superior performance for the high-productivity employees but not for the low-productivity employee.[2] The minimum performance could be some basic duties such as arriving at work on time and performing daily routine assignments. The employer can easily discern if the employee these duties. The superior performance might entail superior creativity or efficiency that are more difficult to measure. For simplicity, Q_L and Q_H are fixed exogenously. The employer evaluates the employee's performance imperfectly. Conditional on the employee's performance being Q_H, the evaluation outcome is Q_H with probability $p_H > \frac{1}{2}$ and Q_L with probability $1 - p_H$; conditional on the employee's performance being Q_L, the evaluation outcome is Q_H with probability $p_L < \frac{1}{2}$ and Q_L with probability $1 - p_L$. The employer can observe perfectly (and therefore deter) any performance below the minimum performance.

The employer pays the employee with a transfer payment T which can vary with the employee's announcement of his productivity and the employer's evaluation. Institutional or legal restrictions impose a lower bound on the employee's compensation. For simplicity, we assume the lower bound of the payment is zero. The employee's utility function is $U = T - e$ which is the payment he receives, *T*, minus the cost of his effort, *e*.

The employer's welfare function is $W(Q,T) = V(Q) - T$ which is her profit from performance Q minus the payment she delivers.

The timing of the model is as follows.

- The employee observes his realized productivity α.
- The employer offers a contract specifying the payment T as a function of the employee's announcement of his productivity and the evaluation outcome.
- The employee announces his productivity.
- The employee chooses effort e, and delivers performance.
- The employer evlauates the employee's performance.
- The employee is paid based upon the evaluation outcome and his ex ante announcement. I abstract from the appeals process until section 5.

3.3 The Optimal Contract with Perfect Evaluation

As a benchmark, I present the optimal contract when the employer can evaluate the employee's performance perfectly. Let T_H denote the payment the employer delivers to the employee when the evaluation of his performance is Q_H. And let T_L denote the payment the employer delivers to the employee when the evaluation of his performance is Q_L. The employer's problem is

$$\underset{T_H, T_L}{Max}\, W = \mu_H \{V(Q_H) - T_H\} + \mu_L \{V(Q_L) - T_L\}$$

subject to:

$$U_H = T_H - e_H \geq 0; \qquad \text{IRH}$$

$$U_L = T_L - e_L \geq 0; \qquad \text{IRL}$$

$$U_H \geq T_L - e(\alpha_H, Q_L); \qquad \text{ICH}$$

$$U_L \geq T_H - e(\alpha_L, Q_H); \qquad \text{ICL}$$

$T_H \geq 0$; and LLH

$T_L \geq 0$. LLL

Constraints IRH and IRL (the individual rationality constraints) guarantee the participation of the employee, regardless of his productivity. Constraints ICH and ICL (the incentive compatibility constraints) ensure that the employee achieves the desired performance according to his productivity. Constraints LLH and LLL ensure all payments to the employee are nonnegative.

The optimal payment structure is characterized by the following equations:

$$T_L = e_L \text{; and} \tag{3-1}$$

$$T_H = e(\alpha_H, Q_H) + (e(\alpha_L, Q_L) - e(\alpha_H, Q_L)). \tag{3-2}$$

Equation 3-1 indicates that the low-productivity employee receives no rent. Equation 3-2 implies that the high-productivity employee receives positive rent because of his private information about his superior productivity. I will call the optimal outcome (contract) in this setting, where the employer evaluates the employee's performance perfectly, the second best outcome (contract). The optimal payments to the employee for superior performance and minimum performance in this setting are denoted as T_H^{**} and T_L^{**}, respectively. Note that limits on liability are not constraining when the performance evaluation is perfect.

3.4 The Optimal Contract with Imperfect Evaluation

Now consider the optimal contract when the employer cannot evaluate the employee's performance perfectly. Before formally model the employer's problem, I present an observation regarding the optimal mechanism.

Observation 1. The employer evaluates the employee's performance only when he claims to be a high-productivity employee.

The intuition behind Observation 1 is the following. The employee is required to deliver minimum performance when he claims to be a low-productivity employee. The employee has no incentive to deliver superior performance, because higher performance demands higher effort. Therefore, evaluating the employee's performance when he claims to be a low-productivity employee is unnecessary, and only invites potential errors given the performance evaluation is imperfect.

Let T_H^H and T_L^H denote the payment for an employee who claims to be a high-productivity employee when he is found to have delivered superior performance or minimum performance, respectively; and let T^L denote the payment for an employee who claims to be a low-productivity employee. Then the employer's problem, labeled [P-NA], is

$$\underset{T_H^H, T_L^H, T^L}{Max}\, W = \mu_H \left\{ V(Q_H) - p_H T_H^H - (1-p_H) T_L^H \right\} + \mu_L \left\{ V(Q_L) - T^L \right\}$$

subject to:

$$U_H \equiv p_H T_H^H + (1-p_H) T_L^H - e(\alpha_H, Q_H) \geq 0; \qquad \text{IRH}$$

$$U_L \equiv T^L - e(\alpha_L, Q_L) \geq 0; \qquad \text{IRL}$$

$$U_H \geq p_L T_H^H + (1-p_L) T_L^H - e(\alpha_H, Q_L); \qquad \text{ICH1}$$

$$U_L \geq T^L - e(\alpha_L, Q_H); \qquad \text{ICL1}$$

$$U_H \geq T^L - e(\alpha_H, Q_H); \qquad \text{ICH2}$$

$$U_L \geq p_L T_H^H + (1-p_L) T_L^H - e(\alpha_L, Q_L); \qquad \text{ICL2}$$

$U_H \geq T^L - e(\alpha_H, Q_L)$; ICH3

$U_L \geq p_H T_H^H + (1 - p_H) T_L^H - e(\alpha_L, Q_H)$; ICL3

$T_H^H \geq 0$; LLHH

$T_L^H \geq 0$; and LLHL

$T^L \geq 0$. LLL

As in the previous model, Constraints IRH and IRL guarantee the participation of the employee regardless of his productivity. Constraints ICH1-3 and ICL1-3 ensure the employee truthfully announces his productivity and delivers corresponding performance. Constraints LLHH, LLHL and LLL impose limits on the employee's liability.

Notice that, without limits on liability (i.e., ignoring constraints LLHH, LLHL and LLL.), the optimal payment structure would be:

$T^L = e(\alpha_L, Q_L)$; and (3-3)

$$p_H T_H^H + (1 - p_H) T_L^H = e(\alpha_H, Q_H) + (e(\alpha_L, Q_L) - e(\alpha_H, Q_L)). \tag{3-4}$$

Equations 3-3 and 3-4 indicate that $T^L = T_L^{**}$ and $p_H T_H^H + (1 - p_H) T_L^H = T_H^{**}$, which imply that the employee receives the same expected payment as when the performance evaluation is perfect. Therefore, in expectation, the employer's inability to evaluate the employee's performance perfectly would have no effect on her expected welfare. However, when p_H and p_L approach $\frac{1}{2}$, so that the evaluation becomes extremely noisy, T_H^H must be extremely large and T_L^H must be extremely negative in an optimal contract. In other words, the employee receives a very large reward when he is found to have delivered superior performance and suffers a very large penalty when he is found to have delivered minimum performance. Such payment structure is not feasible when institutional or legal restrictions impose limits on the magnitude of penalties.

The properties of the optimal contract in [P-NA] are presented in Observation 2.

Observation 2. The solution to [P-NA] has the following features.

(i) When $\frac{p_H}{p_L} \geq 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$, limits on liability and imperfect performance evaluation do not affect the employer's expected welfare.

(ii) When $\frac{p_H}{p_L} < 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$, the employee receives $\frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{p_H - p_L}$ when evaluation reveals superior performance, and zero when the evaluation reveals minimum performance. The employee receives positive expected rent regardless of his productivity.

(iii) An employee who admits to have low-productivity receives a fixed and positive payment for his performance.

To understand Observation 2, it is important to understand how the imperfect evaluation affects the employee's behavior. When the performance evaluation is imperfect, a high-productivity employee may exaggerate his performance when he actually delivers only minimum performance, and a low-productivity employee may exaggerate both his productivity and performance. Consider the ratio of the probabilities that the evaluation reveals superior performance when the employee has delivered superior performance versus when he has delivered minimum performance ($\frac{p_H}{p_L}$) as a measurement of the evaluation accuracy. When the evaluation is relatively accurate ($\frac{p_H}{p_L}$ is large), the occurrence of evaluation errors is relatively rare. Therefore, the employer can ensure the employee truthfully announces his productivity and delivers corresponding performance by imposing a relatively small penalty when the evaluation reveals minimum performance. The same is true when the difference between the two performance standards is relatively small so that the incremental effort the high-productivity employee must exert to achieve the superior performance ($e(\alpha_H, Q_H) - e(\alpha_H, Q_L)$) is relatively small. Then the employer can induce the superior performance from the high-productivity employee with a relatively small penalty when the employee is found to have delivered minimum performance. Furthermore, when the low-productivity employee must exert substantial effort to achieve minimum performance (i.e., when $e(\alpha_L, Q_L)$ is large), the employer must promise him a large payment to induce his participation. Hence, a relatively small penalty when the evaluation reveals minimum performance is sufficient to secure a low-productivity employee's truthful announcement of his productivity. As a result, when $\frac{p_H}{p_L} \geq 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$, limits on liability do not reduce the employer's expected welfare.

In contrast, when $\frac{p_H}{p_L} < 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$, the performance evaluation is relatively inaccurate, the incremental effort the high-productivity employee must exert to achieve the superior performance ($e(\alpha_H, Q_H) - e(\alpha_H, Q_L)$) is relatively large, and the effort the low-productivity employee must exert to achieve minimum performance is relatively small. Consequently, the employer would have to either impose a large penalty when the evaluation reveals minimum performance or raise her payments in other occasions, in order to induce the desired performance from the employee. When large penalties are not feasible, the employer has to deliver a larger expected payment than in the second-best contract. Consequently, the employee receives positive rent regardless of his productivity.

Furthermore, to induce a low-productivity employee's participation and deter him from exaggerating his productivity and performance, the employer must promise a positive payment to a low-productivity employee for his performance (minimum performance). As discussed earlier, there is no need to evaluate the employee's performance when he claims to be a low-productivity employee. Therefore, an employee who claims to have low-productivity receives a fixed payment independent of performance evaluations.

To best demonstrate the effect of the appeal process, the rest of the paper focuses on situations where imperfect evaluation and limits on liability are constraining. In other words, Assumption 1 is made for the rest of the paper.

Assumption 1. $\frac{p_H}{p_L} < 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$.

3.5 The Appeals Process

When the performance evaluation is imperfect, the employer may inadvertently penalize an employee who has delivered superior performance and reward an employee who has delivered minimum performance. Further, limits on liability restrict the employer from imposing large penalty when the employee is found to have delivered minimum performance. Consequently, imperfect evaluation and limits on liability together increase the employer's cost of securing the employee's compliance with performance standards.

The appeals process has been widely adopted in settings such as administrative agencies, regulatory authorities, sports organizations and companies, etc. I examine the appeals process that allows the employee to lodge an appeal when he is found to have delivered only minimum performance. Upon the employee's appeal, the employer launches an investigation about the employee's performance at certain cost. Call this setting "the appeals setting".

When the employee has achieved superior performance, the investigation in the appeals process reveals superior performance with probability $a_H > \frac{1}{2}$, and reveals minimum performance with probability $1 - a_H$. When the employee has delivered minimum performance, the investigation reveals superior performance with probability $a_L < \frac{1}{2}$ and reveals minimum performance with probability $1 - a_L$. Let C_A denote the total cost of the appeals process that includes the relevant cost of both the employer and the appellant. Let T_H^A and T_L^A denote the payments for superior performance and minimum performance in the appeals process, respectively. Denote the share of the cost of the appeals process borne by the employer as r_A. The sequence of actions of the employer and the employee in this setting is summarized in Figure 3-1.

Before proceeding, I present an observation regarding the appeals process.

Observation 3. In the optimal appeals process, an employee who has delivered minimum performance never appeals.[3]

Suppose an employee who has delivered minimum performance appeals when the initial evaluation reveals minimum performance. The expected payoff the employee receives in the appeals process is $(1 - a_L)T_L^A + a_L T_H^A - (1 - r_A)C_A$. Rather than admitting an appeal, the employer will prefer to pay the employee $(1 - a_L)T_L^A + a_L T_H^A - (1 - r_A)C_A$ in the initial stage when he is found to have delivered minimum performance. Doing so

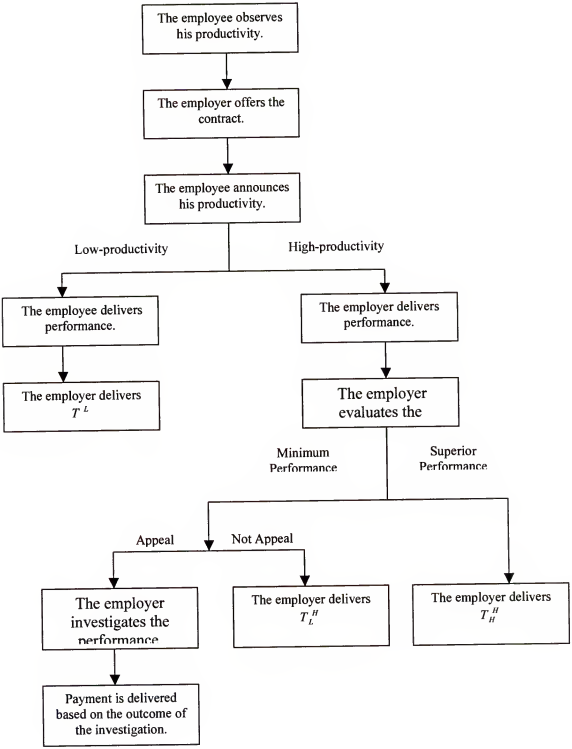
The employee observes his productivity.
The employer offers the contract.
The employee announces his productivity.
Low-productivity
High-productivity
The employee delivers performance.
The employer delivers T^L
The employer delivers performance.
The employer evaluates the
Minimum Performance
Superior Performance
Appeal
Not Appeal
The employer investigates the performance
The employer delivers T_L^H
The employer delivers T_H^H
Payment is delivered based on the outcome of the investigation.

Figure 3-1. Sequence of actions

does not alter either the expected payment received by the employee nor his incentive to deliver performance, but avoids the cost of the appeals process that would be incurred if the low-productivity employee appeals. Therefore, an employee who has delivered minimum performance never appeals in the optimal appeals process.

Given Observation 3, the employer's problem in the appeals setting, labeled [P-A], can be modeled as follows:

$$Max\, W = \mu_H \{V(Q_{H,}) - p_H T_H^H - (1-p_H)[a_H T_H^A + (1-a_H)T_L^A + r_A C_A]\} + \mu_L \{V(Q_L) - T^L\}$$

subject to

$$U_H \equiv p_H T_H^H + (1-p_H)[a_H T_H^A + (1-a_H)T_L^A - (1-r_A)C_A] - e(\alpha_H, Q_H) \geq 0; \text{IRH}$$

$$U_L \equiv T^L - e(\alpha_L, Q_L) \geq 0; \qquad \text{IRL}$$

$$U_H \geq p_L T_H^H + (1-p_L)T_L^H - e(\alpha_H, Q_L); \qquad \text{ICH1}$$

$$U_L \geq T^L - e(\alpha_L, Q_H); \qquad \text{ICL1}$$

$$U_H \geq T^L - e(\alpha_H, Q_H); \qquad \text{ICH2}$$

$$U_L \geq p_L T_H^H + (1-p_L)T_L^H - e(\alpha_L, Q_L); \qquad \text{ICL2}$$

$$U_H \geq T^L - e(\alpha_H, Q_L); \qquad \text{ICH3}$$

$$U_L \geq p_H T_H^H + (1-p_H)[a_H T_H^A + (1-a_H)T_L^A - (1-r_A)C_A] - e(\alpha_L, Q_H); \qquad \text{ICL3}$$

$$T_L^H \geq (1-a_L)T_L^A + a_L T_H^A - (1-r_A)C_A; \qquad \text{ICA}$$

$$T_H^H \geq 0; \qquad \text{LLHH}$$

$$T_L^H \geq 0; \qquad \text{LLHL}$$

$$T^L \geq 0; \qquad \text{LLL}$$

$$T_H^A \geq 0; \text{ and} \qquad \text{LLAH}$$

$T_L^A \geq 0$. LLAL

With probability μ_H, the employee has high-productivity and achieves superior performance. Initially, the employer finds the employee has delivered superior performance and pays him T_H^H with probability p_H, and finds he has delivered minimum performance and pays him T_L^H with probability $1-p_H$. When the high-productivity employee is found to have delivered minimum performance, he rejects payment T_L^H and lodges an appeal at a cost of $(1-r_A)C_A$. In the appeals process, the employer investigates the employee's performance. The investigation entails a total cost of C_A. With probability a_H, the employer finds the high-productivity employee's performance superior in the investigation and delivers payment T_H^A; with probability a_L, she finds the high-productivity employee has delivered minimum performance and pays him T_L^A. With probability μ_L, the employee has low-productivity and delivers minimum performance. Then the employer delivers payment T^L. Constraints IRH and IRL are the individual rationality constraints, which ensure the participation of the employee regardless of his productivity. Constraints ICH1-3 and ICL1-3 are the incentive compatibility constraints, which ensure the employee truthfully announces his productivity and delivers desired performance. Constraint ICA guarantees an employee who has delivered minimum performance does not appeal. Constraints LLHH, LLHL, LLL, LLAH and LLAL ensure the payments are nonnegative in both the initial stage and the appeals process.

Denote the maximum welfare the employer can realize in [P-A] and [P-NA] as $\overline{W}^A$ and $\overline{W}$, respectively. The employer's problem is to maximize $\{\overline{W}^A, \overline{W}\}$.

3.5.1 Costless Appeals Process

As a benchmark, first consider an appeals process involving no cost (i.e., $C_A = 0$). In this case, the merits of admitting appeals depend solely on how much the addition of the appeal process improves the evaluation accuracy. The properties of the appeals process depend on the accuracy of the appeals process relative to the accuracy of the initial evaluation, as Proposition 1 reveals.

Proposition 1. When the appeals process is costless, the solution to [P-A] has the following features:

a The employer implements an appeals process only when $\frac{a_H}{a_L} \geq \frac{p_H(1-p_L)}{p_L(1-p_H)}$.[3]

b The employer delivers no payment when the initial evaluation reveals superior performance, but a positive payment when the initial evaluation reveals minimum performance.

c In the appeal process, the employer delivers a large payment for superior performance, but no payment for minimum performance.

d The employee who claims to have low-productivity receives a fixed payment independent of performance evaluations.

e Increased accuracy of the initial evaluation can reduce he employer's welfare.

f When the appeals process is sufficiently accurate, the employer achieves the second-best outcome.

To understand the conclusions drawn in Proposition 1, consider a situation where the limited liability constraints bind. Without the appeals process, the employee receives T_H^H with probability p_H when he delivers superior performance, and with probability p_L when he delivers minimum performance. When the employee is allowed to appeal, the employee receives T_H^A with probability $[1-p_H]a_H$ when he delivers superior performance, and with probability $[1-p_L]a_L$ when he delivers minimum performance.

When $\frac{a_H}{a_L} < \frac{p_H(1-p_L)}{p_L(1-p_H)}$, implementing the appeals process actually increases the likelihood of rewarding an employee who has delivered only minimum performance. In this case, the employer denies any appeals and rewards superior performance in the initial stage.

When $\frac{a_H}{a_L} > \frac{p_H(1-p_L)}{p_L(1-p_H)}$, implementing the appeals process increases the likelihood of rewarding an employee who has delivered superior performance and reduces the employer's expected payment by

$[e(\alpha_{H,}Q_H) - e(\alpha_{H,}Q_L)][\frac{1}{\frac{p_H}{p_L}-1} - \frac{1}{\frac{(1-p_H)a_H}{(1-p_L)a_L}-1}]$. In this case, the employer prefers to reward the employee in the appeals process. As a result, the employer delivers no payment for superior performance in the initial stage, but a large payment for superior performance in the appeals process. Doing so best limits the employee's rent resulting from evaluation errors. Meanwhile, the employer delivers a positive payment for minimum performance in the initial stage, but no payment for minimum performance in the appeal process. Doing so deters the employee from appealing when he has delivered minimum performance. Furthermore, the employer's welfare decreases as the accuracy of the initial evaluation increases. This is because the employee appeals only when he is initially found to have delivered minimum performance. As the evaluation in the initial stage becomes more accurate, the employee's performance is less likely found to be low when he has delivered superior performance, and is more likely found to be low when he has delivered minimum performance. Therefore, increased accuracy of initial evaluation reduces the employee's opportunity to appeal and get rewarded in the appeals process when he has delivered superior performance, but increases his opportunity to get rewarded in the appeals process when he has delivered minimum performance. Consequently, increased accuracy of the initial evaluation can reduce the employer's welfare.

In contrast, the employer's welfare always increases in the accuracy of the appeals process. When $\frac{a_H}{a_L} \geq \left[1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}\right] \frac{1 - p_L}{1 - p_H}$, the employer achieves the second-best outcome.

3.5.2 Costly Appeals Process

When the appeal process is costly, the employer's welfare will depend on the cost of the process, the allocation of the cost between the employer and the appellant, and the accuracy of the appeals process. Proposition 2 characterizes the optimal cost allocation between parties in an appeals process.

Proposition 2. In the appeals setting, it is desirable to impose all the cost of the appeals process on the appellant.[4]

The intuition underlying Proposition 2 is straightforward. Since the investigation in the appeals process is more like to reveal superior performance when the appellant has delivered superior performance than when he has delivered minimum performance, an employee who has delivered superior performance receives higher expected payment from appealing than one who has not. Because the employee appeals only if his expected gain from appealing is larger than his cost of appealing, imposing a larger share of the cost on the appellant helps prevent an employee who has delivered only minimum performance from appealing. Therefore, the employer always prefers the appellant to bear all the cost of the appeals process. Notice that the employee's cost of appealing can be viewed as a forfeitable bond that must be posted in order to appeal. This forfeitable bond relaxes the limited liability constraint in the appeals process. We will refer to this effect of the appeals process as the liability effect of the appeals process.

Although Proposition 2 suggests that it is optimal for the principal to impose all the cost of the appeals process on the appellant, in many settings, especially administrative and regulatory settings, the principal is often restricted from doing so for political or social reasons. So I will consider r_A as exogenous for the employer in the model and examine how r_A affects the properties of an appeals process.

Proposition 3 characterizes the upper bound of the cost of the appeals process for implementing the appeals process to be optimal.

Proposition 3. The employer optimally denies any appeals when

$$C_A > \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)]p_L - (p_H - p_L)e(\alpha_L, Q_L)}{\mu(1 - p_H)(p_H - p_L)}.$$

The intuition behind Proposition 3 is the following. The employer cannot possibly achieve the desired performance levels without making expected payments that are at least as high as in the second-best contract. Therefore, the maximum value of an appeals process is $\frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)]p_L - (p_H - p_L)e(\alpha_L, Q_L)}{p_H - p_L}$, which is the difference between the employer's expected payments in the second-best contract and in an optimal contract without the appeals process. The employer's expected cost of implementing the appeals process is $\mu_H(1 - p_H)C_A$, where $\mu_H(1 - p_H)$ is the possibility that an appeal occurs. Therefore, when $C_A > \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)]p_L - (p_H - p_L)e(\alpha_L, Q_L)}{\mu(1 - p_H)(p_H - p_L)}$, the employer's cost of implementing the appeals process outweighs her benefit from the appeals process and it is not optimal to implement an appeals process no matter how accurate it is.

When $C_A \le \frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]p_L-(p_H-p_L)e(\alpha_L,Q_L)}{\mu(1-p_H)(p_H-p_L)}$, the properties of the optimal contract depend upon the accuracy and the cost of the appeals process. Table 3-1 identifies five main categories regarding the accuracy and the cost of the appeals process. The properties of the optimal appeals process are different in each of these categories.

When the High-accuracy Condition, Medium-accuracy/High-cost condition, or Low-accuracy/High-cost condition holds, the appeals process enables the employer to fully separate employees who have delivered different level of performance, either because of its high accuracy or because of its high cost. Consequently, limits on liability are not constraining and the employee receives the same expected payoff as when the evaluation is perfect.

In contrast, limits on liability are constraining when the Low-accuracy/Low-cost Condition or Medium-accuracy/Low-cost Condition holds. Proposition 4 and Proposition 5 present the properties of the optimal appeals process under the Low-accuracy/Low-cost Condition and the Medium-accuracy/ Low-cost Condition, respectively.

Proposition 4. When the Low-accuracy /Low-cost Condition holds, the solution to [P-A] has the following features

a The employer delivers a positive payment when the initial evaluation reveals superior performance but no payment when the initial evaluation reveals minimum performance.

b The employer delivers a positive payment for superior performance but no payment for minimum performance in the appeal process.

Table 3-1. Conditions of the appeal process

Conditions	Accuracy	Cost
Low-accuracy/Low-cost Condition	$\frac{a_H}{a_L} < \frac{p_H(1-p_L)}{p_L(1-p_H)}$	$C_A < \frac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]+\left[\frac{p_H}{p_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$
Low-accuracy/High-cost Condition	$\frac{a_H}{a_L} < \frac{p_H(1-p_L)}{p_L(1-p_H)}$	$C_A \geq \frac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]+\left[\frac{p_H}{p_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$
Medium-accuracy/Low-cost Condition	$\left[1+\frac{e(\alpha_H,Q_H)-e(\alpha_H,Q_L)}{e(\alpha_L,Q_L)}\right]\frac{1-p_L}{1-p_H} > \frac{a_H}{a_L} > \frac{p_H(1-p_L)}{p_L(1-p_H)}$	$C_A < \frac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]+\left[\frac{(1-p_H)a_H}{(1-p_L)a_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$
Medium-accuracy/High-cost Condition	$\left[1+\frac{e(\alpha_H,Q_H)-e(\alpha_H,Q_L)}{e(\alpha_L,Q_L)}\right]\frac{1-p_L}{1-p_H} > \frac{a_H}{a_L} \geq \frac{p_H(1-p_L)}{p_L(1-p_H)}$	$C_A \geq \frac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]+\left[\frac{(1-p_H)a_H}{(1-p_L)a_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$
High-accuracy Condition	$\frac{a_H}{a_L} \geq \left[1+\frac{e(\alpha_H,Q_H)-e(\alpha_H,Q_L)}{e(\alpha_L,Q_L)}\right]\frac{1-p_L}{1-p_H}$	

c The employer's welfare increases as the cost of the appeals process increases when she can impose a large share of the cost on the appellant.

d The employer's welfare increases as the accuracy of the initial evaluation or the appeals process increases.

e The employer optimally denies any appeals when she cannot impose a large share of the cost of the appeals process on the appellant.

In the case of a costless appeals process, it has been shown that implementing an appeals process increases the likelihood of rewarding an employee who has delivered only minimum performance and therefore increases the employer's expected payment, when $\frac{a_H}{a_L} < \frac{p_H(1-p_L)}{p_L(1-p_H)}$. Hence, the employer should reward the employee in the initial stage and preclude appeals by offering no reward if an appeal is lodged. However, when the appeals process is costly, the cost of the appeals process born by the appellant functions as a forfeitable bond, which relaxes the limited liability constraint in the appeals process. The appeals process becomes useful for the employer because of the associated enhanced ability to penalize the employee when he is found to have delivered minimum performance in the appeals process. The employer makes full use of the appeals process by delivering no payment (forfeiting the appellant's bond) when minimum performance is found but delivering a positive payment when superior performance is found in the appeals process. This positive payment is increased up to the point where the employee's expected profit of appealing (the difference between expected payment and expected cost of appealing) is zero if he has delivered minimum performance. This ensures an employee who has delivered minimum performance has no (strict) incentive to appeal. After this point, the limited liability constraint in the appeals process binds, and the employer delivers the rest of the payment in the initial stage as in the costless appeals process. Hence, when the employee claims to be a high-productivity employee, the employer delivers to him a positive payment for superior performance but no payment for minimum performance, both in the initial stage and in the appeals process.

The employer's expected cost of implementing the appeals process has been shown to be $\mu(1-p_H)C_A$. In expectation the appeals process enables the employer to reduce the worker's rent by $\dfrac{(1-p_H)(\frac{a_H}{a_L}-1)(1-r_A)C_A}{\frac{p_H}{p_L}-1}$. Therefore, when $r_A < 1-\mu_H(\frac{p_H}{p_L}-1)\Big/(\frac{a_H}{a_L}-1)$, the employer's welfare increases as the cost of the appeals process increases. However, when $r_A > 1-\mu_H(\frac{p_H}{p_L}-1)\Big/(\frac{a_H}{a_L}-1)$, the appeal process increases the employer's expected total cost (the expected payment plus the expected cost of implementing the appeals process) and the employer's welfare decreases as the cost of the appeals process increases. In this case, the employer optimally denies any appeals. Notice that when r_A is sufficiently small, the appeals process can increase the employer's welfare even when the appeals process itself is less accurate than the initial evaluation.

As $\frac{p_H}{p_L}$ or $\frac{a_H}{a_L}$ increases, the employer becomes less likely to make evaluation errors in either the initial stage or the appeals process. Therefore, the employer's welfare increases as the accuracy of the initial evaluation or the appeals process increases.

Proposition 5. When Medium-accuracy/Low-Cost Condition holds, the solution to [P-A] has the following features a The employer prefers to deliver no payment for superior performance in the initial stage, but a large payment for superior performance in the appeals process.

b The employer delivers a positive payment for minimum performance in the initial stage, but no payment for minimum performance in the appeal process.

c The employer's welfare increases in the cost of the appeals process when she can impose a large share of the cost on the appellant.

d When the employer bears a large share of the cost of the appeal process, she optimally denies any appeals that could incur substantial costs.

e The employer's welfare increases in the accuracy of the appeals process.

f The employer's welfare can decrease in the accuracy of the initial evaluation.

When $\frac{a_H}{a_L} > \frac{p_H(1-p_L)}{p_L(1-p_H)}$, it has been shown that implementing an appeals process increase the likelihood of rewarding superior performance. Consequently, the employer prefers to reward superior performance in the appeals process. Doing so best limits the employee's gain from evaluation errors. Meanwhile, the employer compensates minimum performance in the initial stage to deter an employee who has delivered minimum performance from lodging appeals.

In addition, as discussed earlier, the cost of the appeals process imposed on the appellant helps deter the employee from appealing when he has delivered minimum performance and therefore enables the employer to reward superior performance in the appeals process. Consequently, the cost of the appeals process enables the employer to reduce the employee's rent by $\left[\frac{(p_H - p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L} + 1\right](1-p_L)(1-r_A)C_A$. The employer's expected cost of implementing the appeals process has been shown to be $\mu_H(1-p_H)C_A$. When r_A is sufficiently small, the liability effect of the appeals process is relatively large so that $\left[\frac{(p_H - p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L} + 1\right](1-p_L)(1-r_A) > \mu_H(1-p_H)$. In this case, the employer's welfare increases as the cost of the appeals process increases. However, when r_A is sufficiently large, the liability effect of the appeals process is relatively small so that $\left[\frac{(p_H - p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L} + 1\right](1-p_L)(1-r_A) < \mu_H(1-p_H)$. In this case, the employer's welfare decreases as the cost of the appeals process increases. When the appeals process becomes sufficiently costly, the employer optimally denies any appeals even if the appeals process is quite accurate.

As $\frac{a_H}{a_L}$ increases, the employer is less likely to make evaluation errors in the appeals process, which reduces the employee's rent from evaluation errors. Therefore, the employer's welfare increases as the accuracy of the appeals process increases. However, when C_A are sufficiently small, the employer's welfare can decrease in $\frac{p_H}{p_L}$. This is because the employer prefers to reward superior performance through the appeals process when the cost of implementing the appeals process is small. However, the employee appeals only when he is initially found to have delivered minimum performance. As the evaluation in the initial stage becomes more accurate, the employee's performance is less likely found to be low when he has delivered superior performance, and is more likely found to be low when he has delivered minimum performance. Therefore, increased accuracy of initial evaluation restricts the employer's ability to reward different performance levels differentially through the appeals process, and therefore reduces the employer's welfare.

3.6 Conclusion

This paper examines the effect of the appeals process on incentive contracts in the presence of imperfect performance evaluation and limited liability. Five primary observations emerge from the analysis. First, it is not always optimal to implement an appeals process even if the appeals process is costless and quite accurate. Second, when the appeals process is employed, it is optimal to impose all the cost of the appeals process on the appellant. Third, when the appeals process is sufficiently accurate, the employer delivers no payment when the initial evaluation reveals superior performance but a positive payment when the initial evaluation reveals minimum performance. Fourth, under certain condition, increased initial observation accuracy reduces the employer's welfare. Fifth, the employer's welfare can increase as the cost of the appeals process increases.

This study focuses on the role of the appeals process in securing agents' compliance of performance standards in a principal-agent relationship. This is not to deny the importance of other possible purposes of the appeals process, for instance, enhancing organizational fairness. Social scientists (Moore, 1978; Okun, 1975) and management scholars (Block & Dworkin, 1976; Jacques, 1961; Aram & Salipante, 1981) have long recognized the importance of fairness as a basic requirement for the effective functioning of organizations and the personal satisfaction of the individual they employ. The appeal process enhances fairness in an organization by providing employees opportunities to appeal an employer's judgment and preventing erroneous punishments. When an employer's concern with erroneous punishments is substantial, implementing an appeals process could be optimal even if the appeals process itself is inaccurate. Nevertheless, the qualitative findings regarding the appeals process in this model will mostly carry through when organizational fairness is a concern.

This study also abstracts from several factors that might be included in future research. First, the study assumes that the employer is able to commit to the appeals process. When the employer is not able to commit, there will exist no pure strategy separating equilibrium. This is because the employer has no incentive to carry out an investigation in the appeals process if only an employee who has delivered superior performance appeals.[5] Second, this study focuses on the role of the appeals process in securing compliance with a given (exogenous) set of performance standards. How optimal standards might vary when appeals are permitted warrants further study.

3.7 Notes

1. Picard (1987), Riordan and Sappington (1988), and Caillaud, Guesnerie and Rey (1992) show that the principal can achieve efficient outcomes and fully extract the rent of a risk neutral agent as long as the principal can observe a signal correlated with the agent's private information.
2. In other words, $e(\alpha_H, Q_H) - e(\alpha_H, Q_L) < V(Q_H) - V(Q_L) < e(\alpha_L, Q_H) - e(\alpha_L, Q_L)$. Therefore, it is desirable to induce superior performance from a high-productivity employee and minimum performance from a low-productivity employee.
3. The employer is assumed to be able to commit to her proposed mechanism as in standard principal-agent models.
4. Equivalently, the employer can make the payments in the appeals process unattractive to the worker so that no appeals will occur.
5. Note the cost of the appeals process can be non-monetary resources such as time and effort needed to collect supporting evidences. So it suggests that it is optimal to impose a larger burden of proof on the appellant. It also suggests that, in a regulatory setting, the fact that regulatory hearings usually consume considerable time and resources does not necessarily imply that the process is inefficient. This offers another explanation for "regulatory bureaucracy". Sappington (1986) shows that regulatory bureaucracy, that makes the regulatory agency difficult to discern the firm's costs, creates incentives for the firm to reduce costs when the regulator does not have commitment power.

6. Khalil (1997) analyses a principal-agent model where the principal cannot commit to an auditing policy.

CHAPTER 4
SELECTING COST DISTRIBUTIONS

4.1 Introduction

In standard adverse–selection problems, suppliers typically are assumed to have perfect private information about their costs when contracting. In practice, though, a supplier often possesses only imperfect information at the time he signs a contract or makes a production decision. For instance, builders can only estimate the cost of materials when negotiating a construction contract. Similarly, health care providers know only the distribution of costs for treating a population of patients when contracting with health insurers.

In essence, I ask how a buyer optimally arranges for the exchange of goods with a seller who is privately informed about his cost distribution instead of his actual cost at the time of contracting. This adverse selection problem raises new and interesting questions: First, what is the seller's preference regarding different cost distributions? Second, are the preferences of the buyer and the seller regarding different cost distributions aligned or in conflict? Third, does the buyer prefer contracting with an informed seller or a seller uninformed about his cost distributions?

I examine these issues and the properties of optimal contracts in two different environments. The environments differ primarily according to the nature of the seller's information when he signs the contract and when he makes production decisions. In the first environment, costs are revealed sequentially to the seller. At the time of contracting, the seller is privately informed about his cost distribution. Eventually, just prior to production, he observes a perfect signal which reveals his exact cost. In the second environment, the seller cannot observe his exact cost before production. However, he obtains an imperfect signal of his cost prior to production. At the time of contracting, the seller is privately informed about the distribution of the signal. In both settings, the buyer is unable to observe either the cost (signal) distribution or the realization of the eventual signal the seller receives.

Three main findings emerge from this analysis:

- The seller prefers cost distribution 1 to cost distribution 2 for every implementible contract if and only if distribution 2 dominates distribution 1 in the sense of second order stochastic dominance.
- Optimal contracts offer sellers with preferred cost distributions more discretion in choosing output than sellers with less preferred cost distributions. When the buyer can transfer assets, he offers the preferred seller a buyout contract, in which the seller purchases the buyer's assets. Otherwise the buyer maintains control of his assets.
- The preferences of buyers and sellers are partially aligned. The buyer prefers contracting with a seller more likely to draw his preferred distribution. However, for some settings, the buyer may prefer that the seller does not know the distribution he has drawn. [1]

This analysis is most closely related to Athey and Levin (Athey, S. and Levin, J. 2001. The Value of Information in Monotone Decision Problems, MIT working paper 98-24.) who provide general conditions for ranking information structures in different classes of monotone decision problems. They are concerned primarily with the ranking of information structures. In contrast, I focus on the design of optimal contracts.

This analysis is also related to several other papers. Generally, these papers examine the benefits and costs of dealing with better informed agents. Persico (2000) and Ottaviani and Prat (2001) study the value of disclosing affiliated information in auction and procurement settings. They demonstrate that disclosing affiliated information enables the principal to reduce the rent of the privately informed agent. In contrast, I show a better informed seller makes superior decisions for both himself and the buyer. Lewis and Sappington (1993) study optimal contracts when the supplier may know only his expected costs. This paper extends their analysis to include other forms of imperfect knowledge. Lewis and Sappington (1994) examine a seller's incentive to enable potential buyers to acquire private information about their tastes for the seller's product. The authors demonstrate that either a no revelation or a complete revelation policy is optimal for this setting. I extend their analysis to include instances where the agent may observe an imperfect signal of his preferences.

I describe the central elements of the model in Section 4.2. Section 4.3 investigates the seller's preferences over distributions. Section 4.4 derives optimal contracts. Section 4.5 investigates the buyer's preference for contracting with sellers having access to different cost distributions. Section 4.6 summarizes the findings and discusses possible future research in this area.

4.2 The Model

4.2.1 Description of Buyer and Seller.

A risk–neutral buyer, B, contracts with a risk neutral seller, S, to obtain some quantity, $q \geq 0$, of a good or service. Let $V(q)$ denote B's valuation of q where $V(q)$ is a smooth, increasing, and concave function. The buyer's net utility is $W = V(q) - T$, where T is B's payment to S. The seller's total cost of producing q is $C = C(x, q)$, where $x \in X \subset R$ is a parameter that affects cost. I assume $C_x > 0$, $C_q > 0$, $C_{xq} > 0$, and $C_{xx} < 0$ which implies that total and marginal cost of supply is increasing with x. The seller's surplus is $U = T - C(x, q)$.

The seller's knowledge of supply costs evolves one of in two possible ways.

[SR]: sequential revelation of costs

Initially, *S* privately learns his cost distribution for $x \in [\underline{x}, \bar{x}] = X \subset R$ is $G^i(x)$ for *I* $\in$ *{1, 2, ..., N}*, where $G^i(\cdot)$ is an absolutely continuous cumulative density function. The density $G^i(\cdot)$ is drawn with probability $\mu_i \geq 0$ from the set of possible distributions $\{G^i(\cdot)\}_{i=1,\ldots,N}$. I assume *N=2*, which implies the seller becomes one of two types, S^1 *or* S^2, corresponding to the distribution from which he draws costs *x*. Eventually, prior to production, *S* privately learns the realization of *x*.

[IO]: imperfect observation of costs

Just prior to production, S privately observes a signal $z \in [z, z] = Z \in R$ which is correlated with the cost factor *x*. Define the joint distributions over signals and states: $F^i(x,z)$*: X×Z→[0,1]*, where *I* $\in$ *{1, 2},* as *S*'s information structures. The joint distribution $F^i(x,z)$ is drawn with probability $\mu_i \geq 0$ from the set of possible distributions $\{F^i(\cdot)\}_{i=1,2}$. The seller belongs to one of two types, S^1 or S^2, corresponding to the information structure he possesses. At the time of contracting, *S* and *B* share the same prior for the distribution of the cost factor, *G(x)*, but *S* is privately informed about his information structure.

Let *F(x|z)* be the seller's cost distribution conditional on the observation of z and assume that $F(\cdot|z) < F(\cdot|z)$ for all $x \in (x, x)$ and $z' > z$. In words, higher realizations of the signal are associated with higher realizations of cost in the sense of first order stochastic dominance. Also assume *F(x|z)* is strictly increasing and absolutely continuous in *x*. Let $F^i(z|x)$ be the signal distribution conditional on *x* and let $F^i(x)$ be the marginal distribution of the signal given S^i *'s* prior belief of *x*, *G(x)*, and S^i *'s* information structure $F^i(x,z)$. Assume $F^i(z)$ is an absolutely continuous and strictly increasing cumulative density function. Since posterior beliefs must be consistent with the prior, for all x $\in$ X, $E_z^i[F^i(z|x)] = G(x)$ for I $\in$ {1, 2}. Note that *S* is privately informed about his marginal distribution of the signal, $F^i(z)$, at the time of contracting because he is privately informed about his information structure.

The signal gives rise to an expected cost of supply

$$C(z,q(z)) = \int_X C(x,q(x))dF(z|x)\,. \tag{4-1}$$

Given the assumption on *C(x, q)* and *F(x| z)*, it follows that $C_z > 0$, $C_q > 0$, $C_{qz} > 0$. I further assume $C_{zz} < 0$.

To understand the key difference between the two information settings, consider an example where a construction company negotiates a construction contract with a government agency. In the [SR] setting, the construction company is privately informed about the distribution of its actual cost at the time of contracting. After contracting, the construction company receives perfect information about its actual cost and then makes its production decisions. In the [IO] setting, at the time of contracting, the construction company is privately informed about its distribution of likely signals, i.e. his information structure. After contracting, the construction company obtains a signal that imperfectly reveals information about the cost of production and then makes its production decisions based on its information. Therefore, the two information settings differ in the construction company's private knowledge at the time of contracting and in the quality of its information prior to production.

In both information settings, the buyer cannot observe either the cost (signal) distribution or the realization of the eventual signal the seller receives.

4.2.2 Contracting for Supply

As part of an optimal procurement policy, B offers S a set of contract menus $\{T^i(y), q^i(y)\}_{i=1,2}$ conditioned on the seller's type *i* and the realization of $y \in \{x, z\}$.

For [SR], $y = x$. $T^i(x)$ is the transfer *S* receives and $q^i(x)$ is the quantity *S* is required to supply when he announces he is of type *i*. *S* selects his preferred menu $\{T^i, q^i\}$ based on his private knowledge of the cost distribution. The null offer $\{T^i(x) = 0, q^i(x) = 0\}$ for all x is feasible and it is implemented if *B* decides not to purchase from S^i.

For [IO], $y = z$. The contract menus $\{T^i(z), q^i(z)\}_{i=1,2}$ are conditioned on information structure i and the signal *z* that S^i receives. *S* selects his preferred menu $\{T^i, q^i\}$ based on his private knowledge of the information structure.

4.2.3 Timing of the Model

The timing in both settings is as follows.

- The seller learns the cost distribution or the signal distribution.
- The buyer offers a set of contract menus $\{T^i(y), q^i(y)\}_{i=1,2}$ conditioned on the seller's type *i* and the realization of *y*.
- The seller selects his preferred menu $\{T^i(y), q^i(y)\}$ based on his private knowledge of the cost distribution or the signal distribution.
- The seller observes the signal y and selects his output q.
- Exchange takes place according to the contract.

4.3 Seller's Preferences for Distribution

How do sellers rank different distributions? To answer this question, I first define the class of implementible contracts that govern sellers. A contract $\{T^{i}(y), q^{i}(y)\}_{i=1,2}$ is implementible provided S^{i} selects menu $\{T^{i}(y), q^{i}(y)\}$ and supplies the output $q^{i}(y)$ corresponding to his actual cost realization $y = x$ in the [SR] case and $y = z$ in the [IO] case. Let

$$U^{i}(T^{i}, q^{i}) = E_{y}^{i}[U^{i}(y|T^{i}, q^{i})] \tag{4-2}$$

be S^{i}'s expected net surplus under contract $\{T^{j}, q^{j}\}$, where

$$U^{i}(y|T^{j}, q^{j}) = \max_{y'} T^{j}(y') - C(y, q^{j}(y')) \tag{4-3}$$

is S^{i}'s net surplus under contract $\{T^{j}, q^{j}\}$ given realization y.

Lemma 1. $\{T^{i}(y), q^{i}(y)\}$ is ex post implementible iff for *i, j=1, 2*,

a $\quad U_{y}^{i}(y|T^{i}, q^{i}) = -C_{y}^{i}(y, q^{j}(y))$.

b $\quad q^{i}(y)$ is non increasing.

Lemma 1 and all other formal results not proved in the text are proved in the appendix.

For the class of implementible contracts, S prefers one distribution H^{1} to another H^{2} provided

$$U^{1}(T^{i}, q^{i}) \geq U^{2}(T^{i}, q^{i}) \text{ for } i=1, 2. \tag{4-4}$$

This requires for every implementible contract *{T, q}*,

$$\Delta U = U^{1}(T, q) - U^{2}(T, q) = \int_{y} (T(y) - C(y, q(y))(dH^{1}(y) - dH^{2}(y)) \geq 0. \tag{4-5}$$

Integrating Equation 4-5 by parts implies

$$\Delta U = \int_Y C_y(y,q(y))(dH^1(y) - dH^2(y)) \geq 0$$
$$= \int_Y \{-[C_{yy}(y,q(y)) + C_{yq}(y,q(y))q'(y)]\int_{\underline{y}}^{y}(H^1(\tilde{y}) - H^2(\tilde{y}))d\tilde{y}\}dy \geq 0 \tag{4-6}$$

Since $C_{yy}(y,q(y)) \leq 0$ and $C_{yq}(y,q(y)) > 0$ by assumption and $q'(y) \leq 0$ from Lemma 1, the term in square brackets in the second line of Condition 4-6 is negative. Therefore, Condition 4-6 holds for every implementible contract *{T, q}*, if and only if $\int_{\underline{y}}^{y}(H^1(\tilde{y}) - H^2(\tilde{y}))d\tilde{y} \geq 0$ for all $y \in [\underline{y}, \bar{y}]$, i.e., *$H^2$* second order stochastically dominates *H^1* or $H^2(y) \succ_{SOSD} H^1(y)$. This proves

Proposition 1. S prefers distribution *H^1* to *H^2* for all implementible allocations $\{T(), q()\}$ if and only if $H^2(y) \succ_{SOSD} H^1(y)$.

- **Interpretation of the [SR] case.**

In the [SR] setting, $y = x$ and $H^i = G^i$. A special and transparent case of SOSD arises when *G^2* first order stochastically dominates *G^1*. In that instance, it is not surprising that *S* prefers *G^1* to *G^2*, as the likelihood of lower cost is systematically greater under *G^1*. This is the distributional analogue to the classic adverse selection setting where one seller is a lower cost producer than the other seller.

A more interesting case arises when the distributions are ordered by SOSD but not by FOSD. To illustrate, suppose the expected cost, $E(x_i) = \int_{\underline{x}}^{\bar{x}} x dF^i(x)$ is equal for *G^1* and *G^2*. Then *S* prefers the riskier distribution *G^1*, which implies greater cost variation. This is because *S*'s expected surplus *U( )* is convex in *x* for any implementible allocation. The convexity arises because $C_{xx}(x,q(x)) \leq 0$ and $C_{xq}(x,q(x)) > 0$ by assumption and

$q(x)$ is nonincreasing from part b of Lemma 1. Therefore, by Jensen's inequality, S prefers riskier distributions.

The intuition is as follows. First, in any optimal contracts, the seller is required to supply more output when the cost factor x is small and to supply less output when the cost factor x is large. Therefore, the increase in total cost resulting from increasing the cost factor x by one unit is relatively small compared to the decrease in total cost resulting from reducing the cost factor x by one unit. Consequently, given distributions of x with equal expected value, a distribution with greater variance leads to a lower expected total cost than a more certain distribution with its mass concentrated around its expected value. Second, the marginal effect of the cost factor x on the seller's cost of production is diminishing as x increases. For a given amount of output, the decrease in total cost resulting from reducing the cost factor x by one unit, again, is larger than the increase in total cost resulting from increasing the cost factor x by one unit. Therefore, for distributions of x with equal expected value, a distribution with greater variance leads to lower expected total cost for any given amount of output.

This raises a natural question: what factors would cause one seller to inherit a cost distribution with more variation than another seller? A possible explanation is that some sellers are specialists while others are generalists. For instance, an auto mechanic who specializes in transmissions may have the same cost on average compared to another auto mechanic who has no specializations. However, the former mechanic may excel at addressing any auto failures related to transmissions while performing poorly at other mechanical problems. Another possible explanation is that some suppliers' input costs have greater variance than that of other suppliers. A third possible explanation arises from geographic differences. For example, a farm located in an area with greater weather variation would have greater cost variation in supplying agricultural products.

- **Interpretation of the [IO] case.**

For the [IO] setting, $y = z$ and $H^i(y) = F^i(z)$. Then the condition $H^2(y) \succ_{SOSD} H^1(y)$ requires

$$\int_{\underline{z}}^{z} (F^1(z') - F^2(z'))dz' \geq 0 \text{ for all } z \in [\underline{z}, \bar{z}].^2 \tag{4-7}$$

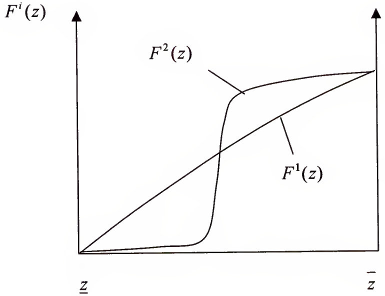

Figure 4–1: Information structures

4.4 Optimal Contracts

Intuitively this condition implies the likelihood the seller observes a signal that would cause him to revise his expectation about costs either up or down is greater under information structure 1 as compared with structure 2. Figure 41 illustrates this intuition. In Figure 4–1, a seller with signal distribution $F^2(z)$ is most likely to observe an average signal which does not provide him much information in addition to his prior belief of x.

In contrast, a seller with signal distribution $F^1(z)$ is likely to observe different signals that enable him to update his belief of x. Since the set of signals observed under both structures are the same and signals are positively correlated with states, this implies the seller is able to accurately update his beliefs about cost more often under structure 1 than under structure 2. As a result, sellers prefer information structure 1 to information structure 2.

This section characterizes optimal ex ante supply contracts. As a baseline for comparison, note that the first–best supply function maximizing the sum of buyer and seller surplus $q^*(y) = \underset{q(y)}{\arg\max}\{V(q(y) - C(y, q(y))\}$ is unique and it is defined by

$$V'(q^*(y)) \leq= C_q(y, q^*(y))(= if\ q^*(y) > 0). \tag{4-8}$$

When the assets of the buyer are transferable, the first best allocation may be implemented by an acquisition contract. The seller purchases the buyer's operation for a fixed fee.

At the time of contracting *S* privately knows his type, S^1 or S^2. *S* does not know the realization of $y = x$ for [SR] or $y = z$ for [IO]. *B* expects the seller is type S^1 with probability μ and type S^2 with probability $1 - \mu$. Under these conditions *B* seeks to

$$\max_{\{T^i(y), q^i(y)\}_{i=1,2}} \mu \int_Y (V(q^1(y)) - V(q^2(y)))dH^1(y) + (1-\mu)\int_Y (V(q^2(y)) - T^2(y))dH^2(y) \tag{4-9}$$

subject to

(a) $U^i_y(y|T^i, q^i) = -C^i_y(y, q^j(y))$;

(b) $q^i(y)$ is non increasing;

(c) $U^i(T^i, q^i) \geq U^i(T^j, q^j)$, where $i \neq j$;

(d) $U^i(T^i, q^i) \geq 0$.

Conditions (a) and (b) are the sufficient and necessary conditions that ensure both types of sellers truthfully report their observation of y. Condition (c) ensures that both types of sellers truthfully report their type *i*. Further, condition (d) ensures the participation of both types of sellers.

Participation of S^2 will be insured if

$$\begin{aligned} U^2(T^2,q^2) &= \int_Y (T^2(y) - C(y,q^2(y))dH^2(y) \\ &= T^2(\bar{y}) - C(\bar{y},q^2(\bar{y})) + \int_Y C_y(y,q^2(y))H^2(y)dy = 0 \end{aligned}, \tag{4-10}$$

implying

$$T^2(\bar{y}) - C(\bar{y},q^2(\bar{y})) = -\int_Y C_y(y,q^2(y))H^2(y)dy\,. \tag{4-11}$$

The incentive compatibility Condition c of Lemma 1 requires S^1 to earn expected surplus

$$U^1(T^1,q^1) = U^1(T^2,q^2) \tag{4-12 }$$

$$= \int_Y (T^2(y) - C(y,q^2(y))dH^1(y) \tag{4-12a}$$

$$= T^2(\bar{y}) - C(\bar{y},q^2(\bar{y})) + \int_Y C_y(y,q^2(y))H^1(y)dy \tag{4-12b}$$

$$= \int_Y C_y(y,q^2(y))(H^2(y) - H^1(y))dy\,, \tag{4-12c}$$

where Equation 4-12b follows from integration by parts, and Equation 4-12c follows from substituting Equation 4-11 into Equation 4-12b for $T^2(\bar{y}) - C(\bar{y},q^2(\bar{y}))$. It follows from Equation 4-12c that

$$\int_Y T^1(y)dH^1(y) = \int_Y [C(y,q^1(y)) + C_y(y,q^2(y))\frac{H^1(y) - H^2(y)}{h^2(y)}]dH^1(y)\,. \tag{4-13}$$

Substituting Equation 4-11 and Equation 4-13 into Equation 4-9, *B*'s problem becomes

$$\max_{\{q^i(y)\}_{i=1,2}} \mu \int_y (V(q^1(y)) - C(y, q^1(y)))dH^1(y) +$$

$$(1-\mu)\int_y [(V(q^2(y)) - C(y, q^2(y)) - \frac{\mu}{1-\mu} C_y(y, q^2(y)) \frac{H^1(y) - H^2(y)}{h^2(y)}]dH^2(y) \tag{4-14}$$

To avoid unnecessary technical complications I assume the monotonicity condition of Lemma 1 is satisfied in the solution to Equation 4-14. The solution is characterized in the following

Proposition 2.

a $V'(q^1(y) \leq C_q(y, q^1(y))(= \mathit{if} \;\; q^1(y) > 0)$.

b $V'(q^2(y)) \leq C(y, q^2(y)) + \frac{\mu}{1-\mu} C_y(y, q^2(y)) \frac{H^1(y) - H^2(y)}{h^2(y)} (= \mathit{if} \; q^2(y) > 0)$.

Proposition 2 indicates S^1's output is surplus maximizing. In contrast, S^2's production is distorted from the surplus maximizing level to reduce S^1's private information profits. The output distortions *B* implements depend on the relation between the cost distributions H^1 and H^2. I illustrate with two cases of interest

Case 1: $H^1 \geq H^2$ for all *y*.

This setting arises only for [SR] with $y = x$ and $G^1(x) \geq G^2(x)$ for all *x*. Intuitively, it implies likelihood of lower cost is uniformly greater under G^1 than under G^2. It is the distributional analogue to the classic setting where one seller is a lower cost producer than the other producer. In that instance the buyer reduces the high cost seller's output to extract the low cost seller's rents. Similarly, here *B* reduces S^2's output below optimal levels to limit S^1's information rent as illustrated in Figure 4–2. However, both types of sellers produce at optimal level when $x = \underline{x}$ or $\bar{x}$ in this case, different from the classic setting where the seller produces at optimal level only when $x = \underline{x}$.

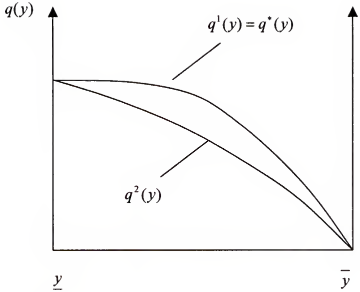

Figure 4–2: Optimal schedules when $H^2(y) \succ_{SOSD} H^1(y)$

The intuition of this result is the following. In the classic setting, the seller is privately informed about his actual cost at the time of contracting. A low–cost seller capture rents by exaggerating his actual cost. To limit the low–cost seller's rent from exaggerating his cost, the buyer optimally reduces the output of a high–cost seller. As a result, except for the seller with the lowest cost, all other sellers produce below the ex post efficient level. In this case, the seller is only privately informed about his cost distribution at the time of contracting. The reason the buyer distorts the supply schedule is not to limit a seller's ex post rent of exaggerating his cost as in the classic setting, because in expectation she can always extract that rent up front if she knows the seller's cost distribution. Instead, the distortion is to extract information rent from a seller with a preferred cost distribution. Raising output $q^2(x)$ by an extra unit increases the buyer's utility by $[V(q^2(x)) - T^2(x)]g^2(x)$. On the other hand, it increases S^2's valuation of the contract by $[V(q^2(x)) - T^2(x)]g^1(x)$ and increases S^1's valuation of the contract by

$C_{yq}(y,q^2(x))[G^1(y)-G^2(y)]$, i.e., it increases S^1's rent of pretending to be S^2 by $C_{yq}(y,q^2(x))[G^1(y)-G^2(y)]$. Therefore, S^1 commands rents when the likelihood that he has cost below a given level is greater, i.e., $G^1(x) > G^2(x)$. As a result of the tradeoff between efficiency and rent extraction, the buyer optimally reduces S^2's output below the efficient level whenever $G^1(x) > G^2(x)$. Since $G^1(\underline{x}) = G^2(\underline{x}) = 0$ and $G^1(\overline{x}) = G^2(\overline{x}) = 1$, S^2 produces at the efficient level when $x = \underline{x}$ or $\overline{x}$.

Case 2: $H^2(y) \succ_{SOSD} H^1(y)$ and H^2 single crosses H^1.

In this setting, H^2 dominates H^1 in the sense of second order stochastic dominance but not first order stochastic dominance. Intuitively, it implies that $H^1(y)$ is a riskier distribution with greater variation than $H^2(y)$. This case accommodates both the [SR] and [IO] settings.

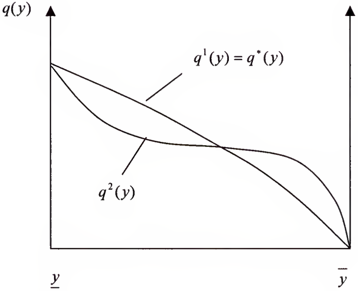

Figure 4–3. Optimal schedules when $H^2(y) \succ_{SOSD} H^1(y)$ and H^2 single crosses H^1

In the [SR] setting, $G^1(x) > G^2(x)$ when cost is low and $G^1(x) < G^2(x)$ when cost is high. As shown in Case 1, raising output $q^2(x)$ by an extra unit increases S^1's information rent by $C_{yq}(y,q^2(x))[G^1(y)-G^2(y)]$. To limit S^1's information rent, *B* reduces S^2's production below the efficient level when $G^1(x)>G^2(x)$ and increases S^2's output above the efficient level when $G^1(x)<G^2(x)$. As a result, S^2 produces below the efficient level when his cost is low and produces above the efficient level when his cost is high. These production distortions reduce S^1's production advantage when costs are low and increases her cost disadvantage when costs are high. The effect of these distortions is to generate a production schedule for S^2 that is less sensitive to costs than the optimal schedule $q^*(y)$ as indicated in the Figure 4-3.

In the [IO] setting, $y=z$ and $H^i(y)=F^i(y)$. In this setting, S^1 is better informed than S^2 since S^1 is more likely to observe informative signals and accurately update his belief of the cost factor *x* compared to S^2. Therefore, S^1 can perform any implementible contract $\{T^i(z),q^i(z)\}_{i=1,2}$ at a lower cost than S^2 does as he is more likely to accurately tailor his output according to the cost of production based upon his information. To extract S^1's information rent of pretending to be S^2, B reduces S^2's production below the efficient levels when S^1 expects costs are low, and increases S^2's output above the efficient levels when S^1 expects costs are high. These production distortions restrain S^1 from fully exploring his information advantage when he performs the contract $\{T^2(z), q^2(z)\}$, therefore limit S^1's information rent of pretending to be S^2. The effect of these distortions is to generate a production schedule for S^2 that is less responsive to his expected costs than the efficient production schedule $q^*(y)$ as indicated in the Figure 4-3.

In the case where *B* may sell her assets, the acquisition of *B* by *S* is feasible. However, Proposition 2 indicates *B* only sells out to S^1. This is because *B* wants to limit the seller's rent from understating his expected profits from acquiring *B*. In order to accomplish this B must distort the supply schedule of seller S^2 and this requires *B* to maintain control of her assets.

4.5 Buyer's Preferences for Contracting with Sellers

4.5.1 Buyer's Preferences for Distribution

What are the buyer's preferences for contracting with sellers having different cost distributions? A seller with a superior distribution can perform more effectively for the buyer. However this advantage must be weighted against the increased information rents such a seller commands.

To investigate this tradeoff I define a seller of type μ, S^{μ} as one who draws the preferred distribution H^1 with probability μ and distribution H^2 with probability $1-\mu$. I assume *B* only knows the sellers' type and not his actual distribution at the time of contracting.

The buyer's expected utility from contracting with S^{μ}, $W(\mu)$ is

$$W(\mu) = \max_{\{q^i()\}_{i=1,2}} \mu AW^1(q^1) + (1+\mu) AW^2(q^2), \tag{4-15}$$

where AW^i the adjusted welfare expression for S^i is given by

$$AW^1(q^1) = \int_y (V(q^1(y)) - V(q^2(y)))dH^1(y) \tag{4-16}$$

$$AW^2(q^2,\mu) = \int_y [(V(q^2(y)) - C(y,q^2(y)) - \frac{\mu}{1-\mu} C_y(y,q^2(y)) \frac{H^1(y)-H^2(y)}{h^2(y)}]dH^2(y) \tag{4-17}$$

Lemma 2 characterizes a key property of *W(μ)*.

Lemma 2. *W(μ)* is strictly convex in *μ*.

Proof: Let

$$W(\mu|\{q^i\}) = \mu A W^1(q^1) + (1+\mu) A W^2(q^2,\mu) \tag{4-18}$$

and denote q^i_μ as the menu maximizing $W(\mu|\{q^i\})$. Note

$$\begin{aligned} W(\mu|\{q^i\}) &= \mu A W^1(q^1_\mu) + (1+\mu) A W^2(q^2_\mu,\mu) \\ &< \mu A W^1(q^1_\mu) + (1+\mu) A W^2(q^2_\mu,0) \\ &< \mu A W^1(q^1_\mu) + (1+\mu) A W^2(q^2_0,0) \\ &< \mu W(1) + (1+\mu) W(0) \end{aligned}, \tag{4-19}$$

where the second line follows from noting *AW²* is decreasing in *μ*, the third line follows because q^1_1 and q^1_0 maximize *AW¹* and *AW²* respectively, and the last line follows after some rearranging.

Suppose *μ = 0* so the seller draws distribution *H²* with certainty. What is the effect on *B*'s expected surplus if *μ* increases slightly?

$$\begin{aligned} W'(0) &= \frac{d}{d\mu_{|\mu=0}} \{\mu A W^1(q^1_1) + (1-\mu) A W^2(q^2_0,\mu) \\ &= \mu A W^1(q^1_1) + A W^2(q^2_0,0) - \int_Y C_y(y, q^2_0(y))(H^1(y) - H^2(y))dy, \\ &= \mu A W^1(q^1_1) + A W^2(q^1_1,0) - \int_Y C_y(y, q^1_1(y))(H^1(y) - H^2(y))dy \\ &= 0 \end{aligned} \tag{4-20}$$

where the third line follows because $q^1_1 = q^1_0$.

Combining Lemma 2 and Equation 4-20 provides Proposition 3.

Proposition 3. *W(μ)* is increasing in *μ*.

Proposition 3 indicates that *B* prefers contracting with more capable sellers, those more likely to draw the preferred distribution. This is because a more capable seller can supply the product with lower expected cost. Although, more capable sellers can always pretend to be less capable sellers and receive information rent, *B* can capture part of the surplus by optimally tailoring the supply schedule for less capable sellers. As a result, *B* receives higher utility when contracting with more capable sellers.

4.5.2 Buyer's Preference for Ex Ante Knowledge of Seller

Proposition 3 demonstrates B prefers contracting with more capable sellers. Does B prefer the seller to know which distribution he has drawn? To answer this I compare B's expected utility when contracting with an informed and uninformed seller.

Expected buyer utility from contracting with an informed seller is $W(\mu)$ defined in Equation 4-15. When contracting with an uninformed seller, *B*'s expected utility, denoted $W^u(\mu)$ is

$$W^u(\mu) = \max_{\{q\}} \int_Y [V(q(y)) - C(y, q(y))](\mu dH^1(y) + (1-\mu) dH^2(y)) . \tag{4-21}$$

Without knowing whether he has drawn H^1 or H^2 the uninformed seller's distribution is the mixture $\mu H^1 + (1-\mu)H^2$. Given this mixed distribution, B designs the menu $\{q\}$ to maximize expected utility as indicated in Equation 4-21. The uninformed seller earns zero information rents. In contrast the informed seller earns a positive profit whenever he draws his preferred distribution.

In the [SR] case where $y = x$, the preferred menus for the uninformed and informed S^1 type seller are the same, $q^u(x) = q_1^1(x)$. Therefore,

$$\begin{aligned} W^u(\mu) &= \mu \int_X [V(q_1^1(x)) - C(x, q_1^1(x))] dG^1(x) + (1-\mu) \int_X [V(q_1^1(x)) - C(x, q_1^1(x))] dG^2(x) \\ &> \mu \int_X [V(q_1^1(x)) - C(x, q_1^1(x))] dG^1(x) \\ &\quad + (1-\mu) \int_X [V(q_1^1(x)) - C(x, q_1^1(x)) - \frac{\mu}{1-\mu} C_x(y, q^2(x)) \frac{G^1(y) - G^2(y)}{g^2(y)}] dG^2(x) \end{aligned}$$

$$
\begin{aligned}
&> \mu \int_X [V(q_1^1(x)) - C(x, q_1^1(x))] dG^1(x) \\
&\quad + (1-\mu) \int_X [V(q_\mu^1(x)) - C(x, q_\mu^1(x)) - \frac{\mu}{1-\mu} C_x(y, q_\mu^2(x)) \frac{G^1(y) - G^2(y)}{g^2(y)}] dG^2(x) \\
&= W(\mu)
\end{aligned}
$$

(4-22)

This proves

Proposition 4. In the [SR] case, *B* prefers contracting with an uninformed seller.

The rationale for this result is as follows. In the [SR] setting, the seller learns the actual realization of his cost before the production, therefore the seller's ex ante knowledge about his cost distribution has no effect on the seller's production decision. When the seller is not informed about his cost distribution, *B* could offer the seller a contract that induces the first–best supply but in expectation fully extracts the seller's rents. On the other hand, an informed seller is able to capture information rent when he draws the preferred cost distribution. Therefore, *B* prefers contracting with an uninformed seller.

In the [IO] setting *B*'s preferences depend on how valuable the more informative information structure is for planning production. To illustrate, imagine *F¹(z)* is the more informative distribution and suppose there exists a much less informative distribution *F(z)* that provides such a poor signal that the buyer does not purchase from a seller with this information structure, as

$$\max_{\{q\}} \mu \int_Z (V(q(z)) - C(Z, q(Z))) d\widetilde{F}(y) \leq 0 . \tag{4-23}$$

Let $F_\lambda^2(y) = \lambda F^1 + (1-\lambda)\widetilde{F}$ represent the second, less informative distribution *S* may draw. This distribution is a mixture of F¹ and F with the weight, *λ ∈ [0,1]* being the measure of similarity between the informative and uninformative information structures. For λ close to 1 there is little additional information gained from observing F^I whereas there is significant information gained from observing F^I when λ is close to 0. Employing this gauge of the value of a more informative structure permits us to partially characterize B's preferences.

Proposition 5. In the [IO] setting, there exists a λ_H and λ_L satisfying $0 < \lambda_L < \lambda_H < 1$ such that

a B prefers contracting with an uninformed seller for $\lambda \geq \lambda_H$.

b B prefers contracting with an informed seller for $\lambda \leq \lambda_L$.

In the [IO] setting B faces a tradeoff between information rent and production efficiency. When the seller is informed about his information structure, the buyer could enhance efficiency by offering a type–1 seller with the preferred information structure a more flexible supply schedule compared to the schedule offered to seller type–2. However, a type–1 seller could capture rents from his private knowledge. When a seller is uninformed the buyer cannot tailor the supply schedule to the quality of the seller's information. Nonetheless the buyer may fully extract the seller's expected rents. When λ is close to 1, the difference between the two information structures is limited. The efficiency gain from dealing with an informed seller is small compared to the additional rent the informed seller captures. Here the buyer prefers contracting with the uninformed seller. When λ is close to 0, the informative information structure provides much better information than the uninformative one. Performance improves significantly by knowing the quality of the seller's information. Further, the inferior information structure is so uninformative that the buyer can easily prevent a type–1 seller from mimicing a type–2 seller at minimal cost. The information rent an informed seller may earn is minimal. Therefore, the buyer prefers contracting with an informed seller when λ is close to 0.

4.6 Conclusion

This paper examines how a buyer optimally contracts with a seller who is privately informed of his distribution of costs. I characterize when the seller prefers one distribution to another. Cost distributions are unambiguously ranked according to the second order stochastic dominance ordering. I show this implies sellers prefer riskier cost distributions. Further buyers prefer contracting with sellers having riskier distributions of costs. Optimal contracts offer risky agents greater discretion in choosing output levels, whereas production choices are more limited for suppliers with more certain distribution of costs.

One extension of this research is to applications in which populations of customers are served by a supplier. Contracting for the supply of health services for a population of patients is one such example. In that setting the care provider may be privately informed of his costs of treating the population at the time of contracting. Further, providers may differ in their ability to diagnose illness and to prescribe and provide appropriate treatment. How then does one select among competing care providers differing in their distribution of costs for patient treatment and their knowledge of patients needs? The insights developed here apply to this and related questions of optimal procurement design.

Another extension of this analysis concerns the optimal employment or disposal of productive assets. When should a business entirely dispose of its assets. Theory suggests (Harris and Raviv (1979)) agency problems are easily resolved when a buyer contracts ex ante with a risk neutral supplier before he knows his cost. The buyer optimally sells the supplier business and makes the supplier the residual claimant of all surplus. The supplier then acts efficiently to maximize total surplus. What happens, though, when the supplier's expected profit from purchasing the buyer is unknown? This is a central question addressed in this analysis. Findings in this model may be extended to consider the dissolving of partnerships, and corporate takeovers.

Finally, this approach to ordering suppliers by their distribution of costs may be applied to rank other supplier characteristics. For instance do buyers prefer dealing with sellers who are less risk averse?

4.7 Notes

1. While our analysis is cast in terms of procurement, our central findings pertain as well to suppliers selling to privately informed buyers.

2. Athey and Levin (2000) have derived a more general alternative characterization for ranking information structures for the class of monotone decision problems of which the supplier's problem I consider is a special case. According to Athey–Levin's condition, information structure *1* is more informative than structure *2* provided $F(x|w^2 \le w) \succ_{SOSD} F(x|w^1 \le w)$ for all $w \in [0,1]$, where $w^i = F^i(z)$. Intuitively, this condition states that low realizations of the signal under information structure *1* lead to higher likelihood of low cost compared to the low realizations of the signal under information structure *2*. Therefore, information structure *1* allows decision makers to better adjust supply to match the cost of production.

CHAPTER 5
CONCLUSION

In Chapter 2, 3 and 5, I have studied several issues in Information and Incentive Economics. This chapter summarizes the main findings of these studies.

Chapter 2 examines how a project owner optimally selects a project operator and motivates him to deliver unobservable effort when potential operators have limited wealth and private knowledge of their ability. It shows that wealth constraints have significant effects on the structure of optimal contracts. First, wealth constraints prevent the project owner from receiving the full value of the project and give rise to profit sharing in the equilibrium. Second, wealth constraints can prevent a high-ability potential operator from outbidding his low-ability counterpart. As a result, the project sometimes is assigned to potential operators of lower abilities. Consequently, diluted incentives and ex post allocation inefficiency arise in the equilibrium.

It has also shown that, when the abilities of potential operators are common knowledge, the operator's share of profit can either increase or decrease with his ability, depending on the prevailing production technology. When potential operators are privately informed about their abilities, either a pooling or a separating contract can arise in the equilibrium. Which equilibrium arises depends upon the elasticity of operator's expected profit from the project with respect to the payment for success. Sufficient conditions for separating contracts to arise, and for pooling contracts to arise, were provided. In separating contracts, the more capable potential operator is either selected more often but awarded a smaller share of profit, or selected less often but awarded a larger share of profit.

This analysis extends the work of Lewis and Sappington (LS) (2000b) who analyze a special case of the model considered here. LS adopt a functional form in which the key elasticity does not vary with the operator's ability. Consequently, a separating equilibrium is optimal in the setting analyzed by LS and the more capable operator is always selected more often but awarded a smaller share of profit. However, more generally, pooling contracts and other separating contracts can be optimal as I have demonstrated. My findings are important given that wealth constraints render both pooling contracts and separating contracts in many relevant practical settings.

Chapter 3 examines the effect of the appeals process on optimal incentive contracts in the presence of imperfect performance evaluation and limited liability. It shows that an optimal appeals process possesses several notable features. For example:

- The employer may deny all appeals even if the appeals process is quite accurate and costless.
- The appellant bears all the costs of the appeals process.
- The employee may be paid more initially for minimum performance than for superior performance.
- The employer's welfare can increase as the cost of the appeals process increases.
- More accurate initial evaluations may reduce the employer's welfare.

These features are actually quite intuitive once the role of the appeals process in incentive contracts is understood. Imperfect performance evaluation restricts the employer's ability to reward an employee who has delivered superior performance and penalize an employee who has delivered minimum performance. Consequently, imperfect performance evaluation increases the employer's cost of motivating desired effort levels. The appeals process allows an employee to appeal when he is found to have delivered minimum performance, and therefore improves the employer's ability to reward an employee who has delivered superior performance. However, when the initial evaluation is sufficiently accurate, an employee is very likely to have delivered minimum performance when the initial evaluation reveals minimum performance. Allowing an employee to appeal in this situation is more likely to reward an employee who has delivered minimum performance and therefore reduces the employer's welfare. Consequently, the employer optimally denies any appeals in this situation.

When the appeals process is sufficiently accurate, the employer provides the greatest reward to an employee who is found to have delivered superior performance in the appeals process. Doing so best limits the rent the employee derives from evaluation errors. The employer delivers a positive payment when the employee is found to have delivered minimum performance in the initial stage in this setting. Doing so reduces the incentive of an employee who has delivered minimum performance to appeal. Consequently, the employee may be paid more in the initial stage for minimum performance than for superior performance. As the initial evaluation becomes more accurate, an employee is more likely to have delivered minimum performance than superior performance when the initial evaluation reveals minimum performance. Therefore, increased accuracy provides more opportunity for an employee who has delivered minimum performance to appeal than for an employee who has delivered superior performance, and restricts the employer's ability to reward different performance levels differentially through the appeals process. As a result, the employer's welfare can decrease as the accuracy of the initial evaluation increases.

Institutional or legal restrictions on an employee's liability limit the ability of the employer to penalize employee who has delivered minimum performance. However, the cost of appealing can essentially act as a forfeitable bond that an employee must post in order to appeal. This forfeitable bond helps deter an employee who has delivered minimum performance from appealing. Therefore, it is optimal to impose all the costs of the appeals process on the appellant. When the employer is able to impose a large share of the cost of the appeals process on the appellant, her welfare can increase as the cost of the appeals process increases.

Chapter 3 focuses on the role of the appeals process in securing agents' compliance of performance standards in a principal-agent relationship. This is not to deny the importance of other possible purposes of the appeals process, for instance, enhancing organizational fairness. Social scientists (Moore, 1978; Okun, 1975) and management scholars (Block & Dworkin, 1976; Jacques, 1961; Aram & Salipante, 1981) have long recognized the importance of fairness as a basic requirement for the effective functioning of organizations and the personal satisfaction of the individual they employ. The appeal process enhances fairness in an organization by providing employees opportunities to appeal an employer's judgment and preventing erroneous punishments. When an employer's concern with erroneous punishments is substantial, implementing an appeals process could be optimal even if the appeals process itself is inaccurate. Nevertheless, the qualitative findings regarding the appeals process in this model will mostly carry through when organizational fairness is a concern.

Chapter 4 has examined how a buyer optimally contracts with a seller who is privately informed of his distribution of costs. First, I characterize when the seller prefers one distribution to another. I show that the seller prefers cost distribution 1 to cost distribution 2 for every implementible contract if and only if distribution 2 dominates distribution 1 in the sense of second order stochastic dominance. I demonstrate that this implies sellers prefer riskier cost distributions. Second, I examine the buyer's preference for sellers' cost distribution. I show that the preferences of buyers and sellers regarding seller's cost distributions are partially aligned. The buyer prefers contracting with a seller who is more likely to draw his preferred distribution. However, for some settings, the buyer may prefer that the seller does not know the distribution he has drawn. Third, I derive optimal contracts for these situations. I show that optimal contracts offer sellers with preferred cost distributions more discretion in choosing output than sellers with less preferred cost distributions. When the buyer can transfer assets, he offers the preferred seller a buyout contract, in which the seller purchases the buyer's assets. Otherwise the buyer maintains control of his assets.

APPENDIX A
PROOF OF PROPOSITIONS IN CHAPTER 2

A.1 Proof of Proposition 1

A.1.1 Proof of Property c

Taking the partial derivative of $\prod^P$ with respect to θ and applying the Envelope Theorem provides

$$\frac{\partial \prod^P}{\partial \theta} = \left[p_\theta(\theta, e(\theta,T)) + p_e(\theta, e(\theta,T))\, e_\theta(\theta,T)\right](V-T) > 0 . \tag{A-1}$$

Q.E.D

A.2 Proof of Proposition 2

The first order condition of the project owner's problem is:

$$\frac{\partial \prod^P}{\partial T} = -p(\theta, e(\theta,T)) + (V-T)p_e(\theta, e(\theta,T))\, e_T(\theta,T) = 0 . \tag{A-2}$$

From the operator's problem,

$$p_e(\theta, e(\theta,T)) = 1/T . \tag{A-3}$$

Then,

$$p_e(\theta, e(\theta,T))T = 1 . \tag{A-4}$$

Totally differentiating Equation A-4 and applying the Envelope Theorem provides

$$p_{ee}(\theta, e(\theta,T))Tde + p_e(\theta, e(\theta,T))dT + p_{e\theta}(\theta, e(\theta,T))Td\theta = 0 . \tag{A-5}$$

So,

$$\frac{de}{dT} = -\frac{p_e(\theta,e(\theta,T))}{p_{ee}(\theta,e(\theta,T))T} = -\frac{1}{p_{ee}(\theta,e(\theta,T))T^2} > 0, \tag{A-6}$$

and

$$\frac{de}{d\theta} = -\frac{p_{e\theta}(\theta,e(\theta,T))}{p_{ee}(\theta,e(\theta,T))} > 0. \tag{A-7}$$

Substituting Equations A-4 and A-6 into Equation A-2 implies

$$\frac{\partial \Pi^P}{\partial T} = -p(\theta,e(\theta,T)) - (V-T)\frac{1}{p_{ee}(\theta,e(\theta,T))T^3} = 0. \tag{A-8}$$

Total differentiating Equation A-8 gives

$$\frac{dT}{d\theta} = \frac{-p_e(\theta,e)e_\theta(\theta,T) - p_\theta(\theta,e) + \left[\frac{V-T}{T^3}\right]\left[\frac{p_{eee}(\theta,e)e_\theta(\theta,T) + p_{ee\theta}(\theta,e)}{p_{ee}(\theta,e(\theta,T))^2}\right]}{p_e(\theta,e)e_T(\theta,T) - \left\{\frac{1}{p_{ee}(\theta,e)T^3} + (V-T)\left[\frac{3}{p_{ee}(\theta,e)T^4} + \frac{p_{eee}(\theta,e)e_T(\theta,T)}{p_{ee}(\theta,e)^2T^3}\right]\right\}} \tag{A-9}$$

.

Since $p_\theta(\theta,e)$, $p_e(\theta,e) > 0$, $p_{ee}(\theta,e) < 0$, $p_{eee}(\theta,e) \le 0$ and $p_{ee\theta}(\theta,e) \le 0$, Equation A-9 implies $\frac{dT}{d\theta} < 0$.

Taking the derivative of Equation A-8 with repect to T again provides

$$\frac{\partial^2 \Pi^P}{\partial T^2} = -p_e(\theta,e)e_T(\theta,T) + \left[\frac{3V-2T}{p_{ee}(\theta,e)T^4} + \frac{(V-T)p_{eee}(\theta,e)e_T(\theta,T)}{p_{ee}(\theta,e)^2T^3}\right] < 0, \tag{A-10}$$

which implies that the second-order condition with respect to T is satisfied.

Q.E.D

Lemma 1: In the optimal contract, $\mu_{HL} + \mu_{LH} = 1$.

Proof: Assume that $\mu_{HL} + \mu_{LH} + \varepsilon = 1$ and $0 < \varepsilon < 1$ in the optimal contract. Furthermore, define

$\tau_1 = [q\mu_{HH} + (1-q)\mu_{HL}]/(1-q)\sigma$ and $\tau_2 = [q\mu_{LH} + (1-q)\mu_{LL}]/q\sigma$.

σ is a scalar which satisfies $\sigma \geq \frac{q\mu_{HH} + (1-q)\mu_{HL}}{(1-q)\varepsilon} + \frac{q\mu_{LH} + (1-q)\mu_{LL}}{q\varepsilon}$ so that $0 < \tau_1 + \tau_2 \leq \varepsilon$.

Now define $\mu^{\circ}_{HL} = \mu_{HL} + \tau_1$ and $\mu^{\circ}_{LH} = \mu_{LH} + \tau_2$ and replace μ_{HL} and μ_{LH} in the presumed optimal contract with μ°_{HL} and μ°_{LH} , respectively.

Constraint 2-10 becomes

$$(1 + 1/\sigma)\Pi(\theta_H) \geq (1 + 1/\sigma)[p(\theta_H, e(\theta_H, T_L))T_L - e(\theta_H, T_L)][q\mu_{LH} + (1-q)\mu_{LL}], \tag{A-11}$$

and Constraint 2-11 becomes

$$(1 + 1/\sigma)\Pi(\theta_L) \geq (1 + 1/\sigma)[p(\theta_L, e(\theta_L, T_H))T_H - e(\theta_L, T_H)][q\mu_{HH} + (1-q)\mu_{HL}]. \tag{A.12}$$

Equations A-11 and A-12 imply both Constraints 2-10 and 2-11 still hold. And it is apparent that all the other constraints still hold while the value of Π^P has increased. Therefore $\mu_{HL} + \mu_{LH} + \varepsilon = 1$ can not be part of optimal contract.

Q.E.D.

Lemma 2: In the optimal contract, $\mu_{HH} = \mu_{LL} = 1/2$.

Proof: Assume $\mu_{HH} + \varepsilon = 1/2$ and $0 < \varepsilon < 1/2$ in the optimal contract, and define $\mu^{\circ}_{HH} = \mu_{HH} + \varepsilon = 1/2$ and $\mu^{\circ}_{HL} = \mu_{HL} - \frac{1-q}{q}\varepsilon$. Now replace μ_{HH} and μ_{HL} in the presumed optimal contract with μ°_{HH} and μ°_{HL}. Since $q\mu_{HH} + (1-q)\mu_{HL}$ is the only term in Constraints 2-10 and 2-11 that has μ_{HH} and μ_{HL}, and

$$q\mu^{\circ}_{HH} + (1-q)\mu^{\circ}_{HL} = \frac{1}{2}q + (1-q)(\mu_{HL} - \frac{q}{1-q}\varepsilon) = q(\frac{1}{2} - \varepsilon) + (1-q)\mu_{HL}$$

$$= q\mu_{HH} + (1-q)\mu_{HL}\,. \tag{A-13}$$

Equation A-13 implies both Constraints 2-10 and 2-11 still hold. And it is apparent that all the other constraints holds. Then we check the value of $\prod^{P}$. Since $2q^{2}\mu_{HH} + 2q(1-q)\mu_{HL}$ is the only term in $\prod^{P}$ that has μ_{HH} and μ_{HL},

$$2q^{2}\mu^{\circ}_{HH} + 2q(1-q)\mu^{\circ}_{HL} = 2q^{2}(\mu_{HH} + \varepsilon) + 2q(1-q)(\mu_{HL} - \frac{q}{1-q}\varepsilon)$$

$$= 2q^{2}\mu_{HH} + 2q(1-q)\mu_{HL}\,, \tag{A-14}$$

Equation A-14 implies the value of $\prod^{P}$ are still the same. Therefore replacing μ_{HH} and μ_{HL} in the presumed optimal contract with μ°_{HH} and μ°_{HL} gives us an contract which is equivalent to the original contract.

Since $\mu_{HL} + \mu_{LH} \leq 1$ and $\mu^{\circ}_{HL} = \mu_{HL} - \frac{1-q}{q}\varepsilon$, we know $\mu^{\circ}_{HL} + \mu_{LH} < 1$, which is a contradiction to Lemma 1. Therefore $\mu_{HH} < 1/2$ can not be part of optimal contract.

Applying the same argument to μ_{LL}, we can show that $\mu_{LL} = 1/2$ in the optimal contract.

Q.E.D

Lemma 3: In equilibrium, the project owner receives higher expected surplus when a more capable operator is selected.

First define $\overline{\Pi}^{P}$ as the project owner's expected net return from the optimal pooling contract, and T_H^* and T_L^* as the optimal payments for potential operators when their abilities are publicly observed, where the subscript represents the operator's ability level. For convenience, let

$\pi_H^P = p(\theta_H, e(\theta_H, T_H))(V - T_H)$ and $\pi_L^P = p(\theta_L, e(\theta_L, T_L))(V - T_L)$.

Then project owner's objective function is

$$\Pi^P = \pi_H^P[2q^2\mu_{HH} + 2q(1-q)\mu_{HL}] + \pi_L^P[2(1-q)^2\mu_{LL} + 2q(1-q)\mu_{LH}]. \tag{A-15}$$

Equation A-15 and Lemma 2 imply

$$\Pi^P = \pi_H^P[q^2 + 2q(1-q)\mu_{HL}] + \pi_L^P[(1-q)^2 + 2q(1-q)\mu_{LH}]. \tag{A.16}$$

Suppose $\pi_H^P \le \pi_L^P$ in the optimal contract. Then Equation A-15 implies

$$\Pi^P \le \pi_L^P[q^2 + 2q(1-q)\mu_{HL}] + \pi_L^P[(1-q)^2 + 2q(1-q)\mu_{LH}] = \pi_L^P. \tag{A-17}$$

Since $p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*)$ is the owner's expected net return from a low-ability operator's operation when she can observe potential operators' ability levels,

$$\pi_L^P \le p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*). \tag{A-18}$$

And it is easy to show that

$$p(\theta_H, e(\theta_H, T_L^*))(V - T_L^*) > p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*). \tag{A-19}$$

Equations A-17, A-18 and A-19 imply

$$\Pi^P < p(\theta_H, e(\theta_H, T_L^*))(V - T_L^*)q + p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*)(1-q). \tag{A-20}$$

By definition,

$$\overline{\prod}^{P} \geq p(\theta_H, e(\theta_H, T_L^*))(V - T_L^*)q + p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*)(1-q). \quad \text{(A-21)}$$

Therefore $\prod^P < \overline{\prod}^P$, which implies the presumed solution is not an optimal solution.

Q.E.D.

A.3 Proof of Proposition 3

A.3.1 Proof of Property c

Suppose $T_H > T_L$ in the equilibrium. Then Constraint 2-11 implies that

$$q\mu_{LH} + (1-q)\mu_{LL} > q\mu_{HH} + (1-q)\mu_{HL}. \quad \text{(A-22)}$$

From Lemma 1 and 2, we know $\mu_{HH} = \mu_{LL} = 1/2$ and $\mu_{HL} = 1 - \mu_{LH}$. Then Equation A-22 implies

$$\mu_{HL} < 1/2 \text{ and } \mu_{LH} > 1/2. \quad \text{(A-23)}$$

Also note that Property b in Proposition 1 implies $T_H^* < T_L^*$ and Equation A-10 implies $\dfrac{\partial^2[p(\theta, e(\theta, T))(V-T)]}{\partial T^2} < 0$. (A-24)

Three cases need to be checked.

Case I: $T_H > T_L \geq T_L^*$;

Lemma 4 implies that $\pi_H^P > \pi_L^P$. Therefore Equations A-16 and A-23 imply

$$\prod^P < \pi_H^P[q^2 + 2q(1-q)\frac{1}{2}] + \pi_L^P[(1-q)^2 + 2q(1-q)\frac{1}{2}] = \pi_H^P q + \pi_L^P(1-q)$$

(A-25)

Since $T_H > T_L \geq T_L^* > T_H^*$, Equations A-18 and A-24 imply

$$\pi_H^P q + \pi_L^P(1-q) < p(\theta_H, e(\theta_H, T_L^*))(V - T_L^*)q + p(\theta_L, e(\theta_L, T_L^*))(V - T_L^*)(1-q)$$

$$< \overline{\Pi}^P . \tag{A-26}$$

Therefore $\Pi^P < \overline{\Pi}^P$, which implies the presumed solution is not an optimal solution.

Case II: $T_H^* \geq T_H > T_L$;

From Equation A-25, $\Pi^P < \pi_H^P q + \pi_L^P (1-q)$. Since $T_L^* > T_H^* \geq T_H > T_L$, and by definition $\pi_H^P \leq p(\theta_H, e(\theta_H, T_H^*))(V - T_H^*)$, Equation A-24 implies

$$\pi_H^P q + \pi_L^P (1-q) < p(\theta_H, e(\theta_H, T_H^*))(V - T_H^*)q + p(\theta_L, e(\theta_L, T_H^*))(V - T_H^*)(1-q)$$

$$< \overline{\Pi}^P . \tag{A-27}$$

Therefore $\Pi^P < \overline{\Pi}^P$, which implies the presumed solution is not an optimal solution.

Case III: $T_L^* \geq T_H > T_L \geq T_H^*$.

Again, from Equation A-25, $\Pi^P < \pi_H^P q + \pi_L^P (1-q)$.

Since $T_L^* \geq T_H > T_L \geq T_H^*$, Equation A-24 implies

$$\pi_H^P q + \pi_L^P (1-q) < p(\theta_H, e(\theta_H, \frac{T_H^* + T_L^*}{2}))(V - \frac{T_H^* + T_L^*}{2})q$$

$$+ p(\theta_L, e(\theta_L, \frac{T_H^* + T_L^*}{2}))(V - \frac{T_H^* + T_L^*}{2})q \leq \overline{\Pi}^P . \tag{A-28}$$

Therefore $\Pi^P < \overline{\Pi}^P$, which implies the presumed solution is not an optimal solution.

Q.E.D.

A.4 Proof of Propostion 4

A.4.1 Proof of Property a

Constraint 2-10 requires that

$$\frac{\pi(\theta_H, T_H)}{\pi(\theta_H, T_L)} \geq \frac{q\mu_{LH} + (1-q)\mu_{LL}}{q\mu_{HH} + (1-q)\mu_{HL}}, \tag{A-29}$$

and Constraint 2-11 requires

$$\frac{q\mu_{LH} + (1-q)\mu_{LL}}{q\mu_{HH} + (1-q)\mu_{HL}} \geq \frac{\pi(\theta_L, T_H)}{\pi(\theta_L, T_L)}. \tag{A-30}$$

Therefore, Constraints 2-10 and 2-11 together requires

$$\frac{\pi(\theta_H, T_H)}{\pi(\theta_H, T_L)} \geq \frac{\pi(\theta_L, T_H)}{\pi(\theta_L, T_L)}. \tag{A-31}$$

It can be shown that $\frac{d}{dT}\left(\frac{\pi(\theta_H)}{\pi(\theta_L)}\right) > 0$, when $\frac{dE_{\pi,T}}{d\theta} > 0$. Since $T_H < T_L$ in any separating contracts according to Proposition 2, Condition (A.31) cannot hold when $\frac{d}{dT}\left(\frac{\pi(\theta_H)}{\pi(\theta_L)}\right) > 0$. Therefore, no separating contract is optimal when $\frac{dE_{\pi,T}}{d\theta} > 0$.

Q.E.D

A.4.2 Proof of Property b

Assume that a pooling contract is optimal. Define $\overline{T}$ as the optimal payment for success in the pooling contract. Apparently each potential operator's probability of operating is 1/2.

According to Proposition 2, it is straightforward that $T_L^* > \overline{T} > T_H^*$, where T_H^* and T_L^* are the optimal payment of success for corresponding potential operator when the project owner can observe the potential operator's ability.

Define $T_H \equiv \overline{T} - \Delta T$, where $\overline{T} - T_H^* \geq \Delta T > 0$. We further define $\Delta\mu_{HL}$ so that

$$[p(\theta_H, e(\theta_H, T_H))T_H - e(\theta_H, T_H)]\left[\frac{1}{2} + (1-q)\Delta\mu_{HL}\right] \equiv [p(\theta_H, e(\theta_H, \overline{T}))\overline{T} - e(\theta_H, \overline{T})]\left[\frac{1}{2} - q\Delta\mu_{HL}\right]. \tag{A-32}$$

By continuity,

$$\frac{1}{2} < \frac{1}{2} + \Delta\mu_{HL} < 1 \tag{A-33}$$

as ΔT is sufficiently close to zero.

From Equation A-32,

$$\frac{\frac{1}{2} + (1-q)\Delta\mu_{HL}}{\frac{1}{2} - q\Delta\mu_{HL}} \equiv \frac{p(\theta_H, e(\theta_H, \overline{T}))\overline{T} - e(\theta_H, \overline{T})}{p(\theta_H, e(\theta_H, \overline{T} - \Delta T))(\overline{T} - \Delta T) - e(\theta_H, \overline{T} - \Delta T)}. \tag{A-34}$$

Since $\frac{d}{dT}\left(\frac{\pi(\theta_L)}{\pi(\theta_H)}\right) < 0$,

$$\frac{p(\theta_H, e(\theta_H, \overline{T}))\overline{T} - e(\theta_H, \overline{T})}{p(\theta_H, e(\theta_H, \overline{T} - \Delta T))(\overline{T} - \Delta T) - e(\theta_H, \overline{T} - \Delta T)} > \frac{p(\theta_L, e(\theta_L, \overline{T}))\overline{T} - e(\theta_L, \overline{T})}{p(\theta_L, e(\theta_L, \overline{T} - \Delta T))(\overline{T} - \Delta T) - e(\theta_L, \overline{T} - \Delta T)}. \tag{A-35}$$

Therefore,

$$\frac{\frac{1}{2} + (1-q)\Delta\mu_{HL}}{\frac{1}{2} - q\Delta\mu_{HL}} > \frac{p(\theta_L, e(\theta_L, \overline{T}))\overline{T} - e(\theta_L, \overline{T})}{p(\theta_L, e(\theta_L, \overline{T} - \Delta T))(\overline{T} - \Delta T) - e(\theta_L, \overline{T} - \Delta T)}. \tag{A-36}$$

Furthermore, as $p(\theta_H, e(\theta_H, T_H))(V - T_H) > p(\theta_H, e(\theta_H, \overline{T}))(V - \overline{T})$ and $p(\theta_H, e(\theta_H, T_H))(V - T_H) > p(\theta_L, e(\theta_L, \overline{T}))(V - \overline{T})$, the project owner is strictly better off with a contract in which the payments of success for the high-ability potential operator and the low-ability operator respectively are T_H and $\overline{T}$, and the probabilities of operation are $\mu_{HH} = \mu_{LL} = \frac{1}{2}$, $\mu_{HL} = \frac{1}{2} + \Delta\mu_{HL}$ and $\mu_{LH} = \frac{1}{2} - \Delta\mu_{HL}$. Based upon Equations A-32, A-33 and A-36, It can be readily verified that this new contract satisfies all the constraints.

Therefore, a pooling contract is not optimal.

Q.E.D.

APPENDIX B
PROOF OF PROPOSITIONS IN CHAPTER 3

B.1 The Solution to [P-A]

B.1.1 Costless Appeals Process

It can be readily shown that constraints IRH, ICH1, ICL1, ICH2, ICL3, LLLL, LLL, and LLAH are redundant. Therefore, the Lagrangian of this problem is as follows:

$$\begin{aligned}\mathcal{L} = {} & \mu_H\{V(Q_{H,}) - p_H T_H^H - (1-p_H)[a_H T_H^A + (1-a_H)T_L^A]\} + \mu_L\{V(Q_L) - T^L\} \\ & + \lambda_0\{T^L - [p_L T_H^H + (1-p_L)T_L^H]\} + \lambda_1\{T^L - e(\alpha_L, Q_L)\} \\ & + \lambda_2\{p_H T_H^H + (1-p_H)[a_H T_H^A + (1-a_H)T_L^A] - e(\alpha_H, Q_H) - [T^L - e(\alpha_H, Q_L)]\} \\ & + \lambda_3\{T_L^H - [a_L T_H^A + (1-a_L)T_L^A]\}_L + \lambda_4 T_H^H + \lambda_5 T_H^A + \lambda_6 T_L^A\end{aligned}$$

(B-1)

The first order conditions are:

$$\mathcal{L}_{T_H^H} = -\mu_H p_H - \lambda_0 p_L + \lambda_2 p_H + \lambda_4 = 0 \tag{B-2}$$

$$\mathcal{L}_{T_L^H} = -\lambda_0(1-p_L) + \lambda_3 = 0 \tag{B-3}$$

$$\mathcal{L}_{T^L} = -\mu_L + \lambda_0 + \lambda_1 - \lambda_2 = 0 \tag{B-4}$$

$$\mathcal{L}_{T_H^A} = -\mu_H(1-p_H)a_H + \lambda_2(1-p_H)a_H - \lambda_3 a_L + \lambda_5 = 0 \tag{B-5}$$

$$\mathcal{L}_{T_L^A} = -\mu_H(1-p_H)(1-a_H) + \lambda_2(1-p_H)(1-a_H) - \lambda_3(1-a_L) + \lambda_6 = 0 \tag{B-6}$$

The following seven cases are to be analyzed:

Case I: $\lambda_3 = 0$ and $\lambda_4 = 0$;

Case II: $\lambda_3 = 0$ and $\lambda_4 > 0$;

Case III: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$ and $\lambda_6 > 0$;

Case IV: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$ and $\lambda_6 = 0$;

Case V: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 > 0$ and $\lambda_6 > 0$;

Case VI: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 > 0$ and $\lambda_6 = 0$;

Case VII: $\lambda_3 > 0$ and $\lambda_4 > 0$.

Among the seven cases, Case II, Case IV, Case V and Case VI can be ruled out by contradictions, and therefore only Case I, Case III and Case VII are valid cases.

Case I: $\lambda_3 = 0$ and $\lambda_4 = 0$;

Substituting $\lambda_3 = 0$ and $\lambda_4 = 0$ into Equations B-2, B-3 and B-4 and jointly solving these three equations provides $\lambda_1 = 1$ and $\lambda_2 = \mu_H$. Substituting $\lambda_2 = \mu_H$, $\lambda_3 = 0$ and $\lambda_4 = 0$ into Equations B-5 and B-6 provides $\lambda_5 = 0$ and $\lambda_6 = 0$. $\lambda_1 = 1$ and $\lambda_2 = \mu_H$ imply that the constraints IRL and ICH are binding. Therefore,

$$T^L = e(\alpha_L, Q_L)\text{; and} \tag{B-7}$$

$$p_H T_H^H + (1 - p_H)[a_H T_H^A + (1 - a_H) T_L^A] = e(\alpha_H, Q_H) + (e(\alpha_L, Q_L) - e(\alpha_H, Q_L)). \tag{B-8}$$

Equations B-7 and B-8 indicates the employer is able to in expectation deliver the second-best payoff to the employee regardless of his productivity. For this case to be true, we must have

$$\frac{a_H}{a_L} > \left[1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}\right]\frac{1 - p_L}{1 - p_H}. \tag{B-9}$$

Since we assume $\frac{p_H}{p_L} < 1 + \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{e(\alpha_L, Q_L)}$, this case exists only if

$$\frac{p_H}{p_L} > \frac{(1-p_H)*a_H}{(1-p_L)*a_L}. \tag{B-10}$$

Case III: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$ and $\lambda_6 > 0$;

From Equation B-5, we have

$$\lambda_3 = (\lambda_2 - \mu_H)(1-p_H)\frac{a_H}{a_L}. \tag{B-11}$$

Jointly solving Equations B-2, B-3 and B-4 provides

$$\lambda_3 = (\lambda_2 - \mu_H)(1-p_L)\frac{p_H}{p_L}. \tag{B-12}$$

Since $\lambda_3 > 0$ and $\lambda_2 - \mu_H \neq 0$. Therefore,

$$\frac{p_H}{p_L} = \frac{(1-p_H)*a_H}{(1-p_L)*a_L}. \tag{B-13}$$

In this case, the ratio of the likelihood of rewarding superior performance are the same with or without the appeals process. Hence, the employer receives the same expected welfare with or without the appeals process, and the employee receives positive rents regardless of his productivity.

Case V: $\lambda_3 > 0$ and $\lambda_4 > 0$.

Since $\lambda_4 > 0$, $T_H^H = 0$. Therefore, $T_H^A > 0$ and $\lambda_5 = 0$. Substituting $\lambda_5 = 0$ into Equation B-5 provides

$$\frac{a_L}{a_H}\lambda_3 = (\lambda_2 - \mu_H)(1-p_H). \tag{B-14}$$

Substituting Equation B-14 into Equation B-6 provides

$$\lambda_6 = [(1-a_L)a_H - (1-a_H)a_L]\frac{\lambda_3}{a_H} > 0 \ . \tag{B-15}$$

$\lambda_6 > 0$ suggests that $T_L^A = 0$. In addition, $\lambda_3 > 0$ suggests that $T_L^H = a_L T_H^A$.

Substituting $T_H^H = 0$, $T_L^A = 0$ and $T_L^H = a_L T_H^A$ into constraint ICH3 provides

$$T_H^A = \frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{(1-p_H)a_H - (1-p_L)a_L}. \tag{B-16}$$

Constraints IRL and ICL2 require

$$T_H^A \geq \frac{e(\alpha_L, Q_L)}{(1-p_L)a_L}. \tag{B-17}$$

For Equation B-17 to hold, we must have

$$\frac{e(\alpha_H, Q_H) - e(\alpha_H, Q_L)}{(1-p_H)a_H - (1-p_L)a_L} \geq \frac{e(\alpha_L, Q_L)}{(1-p_L)a_L}. \tag{B-18}$$

Equation B-18 indicates $\lambda_1 = 0$. Substituting $\lambda_1 = 0$ into Equation B-2, B-3, B-4 and B-5 and jointly solving these equations provides

$$\lambda_4 = \frac{p_L(1-p_H)a_H - p_H(1-p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L}. \tag{B-19}$$

Since we assume $\lambda_4 > 0$, we have

$$\frac{p_L(1-p_H)a_H - p_H(1-p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L} > 0 \text{, or equivalently,} \tag{B-20}$$

$$\frac{a_H}{a_L} \geq \frac{p_H(1-p_L)}{p_L(1-p_H)}. \tag{B-21}$$

Substituting Equation B-16 into the principal's objective function provides

$$W=\mu_H V(Q_H)+\mu_L V(Q_L)-\left[\mu_H+\frac{2\mu_H-1}{\dfrac{(1-p_H)a_H}{(1-p_L)a_L}-1}\right]\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right].$$

(B-22)

Equation B-22 implies that W is increasing in $\frac{a_H}{a_L}$ and decreasing in $\frac{p_H}{p_L}$.

B.1.2 Costly Appeals Process.

The Lagrangian of this problem is as follows.

$$\begin{aligned}\mathcal{L}=\;&\mu_H\left\{V(Q_{H,})-p_H T_H^H-(1-p_H)[a_H T_H^A+(1-a_H)T_L^A+r_A C_A]\right\}+\mu_L\left\{V(Q_L)-T^L\right\}\\&+\lambda_0\left\{T^L-[p_L T_H^H+(1-p_L)T_L^H]\right\}+\lambda_1\left\{T^L-e(\alpha_L,Q_L)\right\}\\&+\lambda_2\left\{p_H T_H^H+(1-p_H)[a_H T_H^A+(1-a_H)T_L^A-(1-r_A)C_A]-e(\alpha_H,Q_H)-[T^L-e(\alpha_H,Q_L)]\right\}\\&+\lambda_3\left\{T_L^H-[a_L T_H^A+(1-a_L)T_L^A-(1-r_A)C_A]\right\}_L+\lambda_4 T_H^H+\lambda_5 T_H^A+\lambda_6 T_L^A+\lambda_7 T_L^H\end{aligned}$$

(B-23)

The first order conditions are:

$$\mathcal{L}_{T_H^H}=-\mu_H p_H-\lambda_0 p_L+\lambda_2 p_H+\lambda_4=0 \quad \text{(B-24)}$$

$$\mathcal{L}_{T_L^H}=-\lambda_0(1-p_L)+\lambda_3+\lambda_7=0 \quad \text{(B-25)}$$

$$\mathcal{L}_{T^L}=-\mu_L+\lambda_0+\lambda_1-\lambda_2=0 \quad \text{(B-26)}$$

$$\mathcal{L}_{T_H^A}=-\mu_H(1-p_H)a_H+\lambda_2(1-p_H)a_H-\lambda_3 a_L+\lambda_5=0 \quad \text{(B-27)}$$

$$\mathcal{L}_{T_L^A}=-\mu_H(1-p_H)(1-a_H)+\lambda_2(1-p_H)(1-a_H)-\lambda_3(1-a_L)+\lambda_6=0 \quad \text{(B-28)}$$

$$\mathcal{L}_{r_A}=-\mu_H(1-p_H)C_A+\lambda_2(1-p_H)C_A-\lambda_3 C_A=0 \quad \text{(B-29)}$$

The following eleven cases are to be analyzed:

Case I: $\lambda_3 = 0$, $\lambda_4 = 0$ and $\lambda_7 = 0$;

Case II: $\lambda_3 = 0$, $\lambda_4 = 0$ and $\lambda_7 > 0$;

Case III: $\lambda_3 = 0$, $\lambda_4 > 0$ and $\lambda_7 = 0$;

Case IV: $\lambda_3 = 0$, $\lambda_4 > 0$ and $\lambda_7 > 0$;

Case V: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$, and $\lambda_6 = 0$;

Case VI: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$, $\lambda_6 > 0$ and $\lambda_7 = 0$;

Case VII: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$, $\lambda_6 > 0$ and $\lambda_7 > 0$;

Case VIII: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 > 0$, and $\lambda_6 = 0$;

Case IX: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 > 0$, and $\lambda_6 > 0$;

Case X: $\lambda_3 > 0$, $\lambda_4 > 0$ and $\lambda_7 = 0$;

Case XI: $\lambda_3 > 0$, $\lambda_4 > 0$ and $\lambda_7 > 0$.

Nine of the eleven cases can be ruled out by contradictions, and only Case I, Case VII and Case X are valid cases.

Case I: $\lambda_3 = 0$, $\lambda_4 = 0$ and $\lambda_7 = 0$;

Substituting $\lambda_3 = 0$, $\lambda_4 = 0$ and $\lambda_7 = 0$ into Equations B-24, B-24, and B-25 and jointly solving these three equations provides $\lambda_1 = 1$ and $\lambda_2 = \mu_H$. Substituting $\lambda_2 = \mu_H$, $\lambda_3 = 0$ and $\lambda_4 = 0$ into Equation B-27 and B-28 provides $\lambda_5 = 0$ and $\lambda_6 = 0$.

$\lambda_1 = 1$ and $\lambda_2 = \mu_H$ imply that the constraints IRL and ICH3 are binding.

Therefore,

$T^L = e(\alpha_L, Q_L)$; and (B-30)

$$p_H T_H^H + (1-p_H)[a_H T_H^A + (1-a_H)T_L^A - (1-r_A)C_A] = e(\alpha_H, Q_H) + [e(\alpha_L, Q_L) - e(\alpha_H, Q_L)]$$

(B-31)

Equations B-30 and B-31 indicate the employee in expectation receives the second-best payoff regardless of his productivity. Note that Equation B-29 always holds, in other words, r_A has no effect on the result.

Case VI: $\lambda_3 > 0$, $\lambda_4 = 0$, $\lambda_5 = 0$, $\lambda_6 > 0$ and $\lambda_7 > 0$;

$\lambda_7 > 0$ indicates $T^L = 0$. $\lambda_6 > 0$ indicates $T_L^A = 0$. Furthermore, $\lambda_3 > 0$ indicates $T_L^H = a_L T_H^A - (1 - r_A)C_A$. Therefore,

$$T_H^A = \frac{(1 - r_A)C_A}{a_L}. \tag{B-32}$$

Substituting $\lambda_5 = 0$ into Equation B-27 provides

$$\lambda_2 (1 - p_H) a_H = (1 - p_H) a_H + \lambda_3 a_L, \tag{B-33}$$

which implies $\lambda_2 > 0$ and constraint ICH3 is binding. Therefore,

$$p_H T_H + (1 - p_H)\left[a_H T_H^A - (1 - r_A)C_A\right] - e(\alpha_H, Q_H) = p_L T_H - e(\alpha_H, Q_L) \tag{B-34}$$

Constraint ICL requires $T_H \geq \frac{e(\alpha_L, Q_L)}{p_L}$. Assume

$$T_H = \frac{e(\alpha_L, Q_L)}{p_L}. \tag{B-35}$$

Substituting Equation B-35 into B-34 together provides

$$T_H^A = \frac{\left[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)\right] + \left[\frac{p_H}{p_L} - 1\right] e(\alpha_L, Q_L) + (1 - p_H)(1 - r_A) a_H C_A}{(1 - p_H) a_H}$$

(B-36)

Equations B-32 and B-36 require

$$C_A = \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] + \left[\frac{p_H}{p_L} - 1\right] e(\alpha_L, Q_L)}{(\frac{a_H}{a_L} - 1)(1 - p_H)(1 - r_A)}. \tag{B-37}$$

When Equation B-37 holds, constraint ICA is not binding, therefore, $\lambda_3 = 0$.

The contradiction shows that $T_H = \frac{e(\alpha_H, Q_L)}{p_L}$ is not true.

Assume $T_H > \frac{e(\alpha_L, Q_L)}{p_L}$, then $\lambda_1 = 0$. Substituting $\lambda_1 = 0$ into Equation B-24 provides

$$\lambda_2 = \mu + \frac{p_L}{p_H - p_L} \tag{B-38}$$

Substituting Equation B-38 into Equation B-27 provides

$$\lambda_3 = \frac{1}{a_L}(1 - p_H) a_H (\mu + \frac{p_L}{p_H - p_L}) \frac{a_L}{a_H} - \mu(1 - p_H) \frac{a_L}{a_H}. \tag{B-39}$$

And substituting Equation B-38 and B-39 into Equations B-25 and B-26 provides

$$\lambda_7 (1 - p_L) a_L = p_H (1 - p_L) a_L - p_L (1 - p_H) a_H. \tag{B-40}$$

Since $\lambda_7 > 0$, Equation B-40 implies

$$\frac{a_H}{a_L} < \frac{p_H (1 - p_L)}{p_L (1 - p_H)}. \tag{B-41}$$

$\lambda_3 > 0$ implies

$$T_H^A = \frac{(1 - r_A) C_A}{a_L}. \tag{B-42}$$

$\lambda_2 > 0$ implies

$$T_H = \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] - (1 - p_H)(\frac{a_H}{a_L} - 1)(1 - r_A) C_A}{p_H - p_L}. \tag{B-43}$$

Jointly solving Equations (B-27) and (B-29) provides

$$\lambda_{s_A} = C_A(\frac{a_L}{a_H} - 1)\lambda_3 < 0. \qquad \text{(B-44)}$$

Therefore, $r_A = 0$.

$T_H > \frac{e(\alpha_L, Q_L)}{p_L}$ requires

$$C_A < \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] + \left[\frac{p_H}{p_L} - 1\right] e(\alpha_L, Q_L)}{(\frac{a_H}{a_L} - 1)(1 - p_H)(1 - r_A)}. \qquad \text{(B-45)}$$

Case X: $\lambda_3 > 0$, $\lambda_4 > 0$ and $\lambda_7 > 0$;

Since $\lambda_4 > 0$, $T_H^H = 0$. Therefore, $T_H^A > 0$ and $\lambda_5 = 0$. Substituting $\lambda_5 = 0$ into Equations B-27 and B-28 provides

$$\lambda_6 = \lambda_3 \frac{[(1 - a_L)a_H - (1 - a_H)a_L]}{a_H} > 0. \qquad \text{(B-46)}$$

$\lambda_6 > 0$ implies $T_L^A = 0$.

$\lambda_3 > 0$ implies

$$T_L^H = a_L T_H^A - (1 - r_A)C_A. \qquad \text{(B-47)}$$

From Equation B-27, we have

$$\lambda_2 = \frac{\mu(1 - p_H)a_H + \lambda_3 a_L}{(1 - p_H)a_H} > 0, \qquad \text{(B-48)}$$

i.e., constraint ICH3 is binding. Therefore, we have

$$T_H^A = \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] + (p_L - p_H)(1 - r_A)C_A}{(1 - p_H)a_H - (1 - p_L)a_L}. \qquad \text{(B-49)}$$

Constraint IRL requires

$$T_H^A \geq \frac{e(\alpha_L, Q_L) + (1-p_L)(1-r_A)C_A}{(1-p_L)a_L}. \qquad \text{(B-50)}$$

Therefore,

$$C_A \leq \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] - \left[\frac{(1-p_H)a_H}{(1-p_L)a_L} - 1\right] e(\alpha_L, Q_L)}{(\frac{a_H}{a_L} - 1)(1-p_H)(1-r_A)}. \qquad \text{(B-51)}$$

Assume $C_A = \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] - \left[\frac{(1-p_H)a_H}{(1-p_L)a_L} - 1\right] e(\alpha_L, Q_L)}{(\frac{a_H}{a_L} - 1)(1-p_H)(1-r_A)}$, then

Constraint ICH3 always holds and $\lambda_2 = 0$. The contradiction shows

$$C_A < \frac{[e(\alpha_H, Q_H) - e(\alpha_H, Q_L)] - \left[\frac{(1-p_H)a_H}{(1-p_L)a_L} - 1\right] e(\alpha_L, Q_L)}{(\frac{a_H}{a_L} - 1)(1-p_H)(1-r_A)}. \qquad \text{(B-52)}$$

When Equation B-50 holds, $\lambda_1 = 0$. Substituting $\lambda_1 = 0$ into Equations B-24 and B-25.

From Equations B-24, B-25, B-26 and B-27, we have

$$\lambda_4 = \frac{\mu(1-p_H)a_H + (1-\mu)(1-p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L}. \qquad \text{(B-53)}$$

$\lambda_4 > 0$ requires

$$\frac{p_L(1-p_H)a_H - p_H(1-p_L)a_L}{(1-p_H)a_H - (1-p_L)a_L} > 0 \text{, or equivalently,} \qquad \text{(B-54)}$$

$$\frac{a_H}{a_L} \geq \frac{p_H(1-p_L)}{p_L(1-p_H)}. \qquad \text{(B-55)}$$

It can be shown that $\lambda_{s_A} = \lambda_3(\frac{a_L}{a_H} - 1)C_A < 0$. Therefore, $r_A = 0$.

B.2 Proof of Proposition 4

According to the solution to [P-A], Case VI exists when $\frac{a_H}{a_L} < \frac{p_H(1-p_L)}{p_L(1-p_H)}$ and

$$C_A < \frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-\left[\frac{p_H}{p_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}.$$ Properties a and b have been shown in the analysis of Case VI. Properties c and f have been explained in the text. The proof of Property d is as follows.

Define the principal's expected expense (expected payment plus expected cost of the appeals process) as EX.

$$EX = \left[\mu + \frac{1}{\frac{p_H}{p_L}-1}\right][e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-(1-p_H)\left[\frac{(\frac{a_H}{a_L}-1)(1-r_A)}{\frac{p_H}{p_L}-1}-\mu\right]C_A\,.$$

(B-56)

It can be readily shown that $\frac{dEX}{d\frac{a_H}{a_L}} < 0$.

Differentiating *EX* with respect to p_L provides

$$\frac{dEX}{dp_L} = \frac{\frac{p_H}{p_L^2}}{(\frac{p_H}{p_L}-1)^2}[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-(1-p_H)\frac{\frac{p_H}{p_L^2}(\frac{a_H}{a_L}-1)(1-r_A)}{(\frac{p_H}{p_L}-1)^2}C_A\,.$$

(B-57)

Since $C_A < \dfrac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-[\frac{p_H}{p_L}-1]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$, $\dfrac{dEX}{dp_L}>0$. Therefore, the principal's welfare is decreasing in p_L.

Differentiating EX with respect to p_H provides

$$\frac{dEX}{dp_H}=\frac{-\frac{1}{p_L}}{(\frac{p_H}{p_L}-1)^2}\left\{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)C_A\right\}+\left[\frac{(\frac{a_H}{a_L}-1)(1-r_A)}{\frac{p_H}{p_L}-1}-\mu\right]C_A. \tag{B-58}$$

Substituting $C_A < \dfrac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-[\frac{p_H}{p_L}-1]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$ into Equation B-58, we have

$$\begin{aligned}\frac{dEX}{dp_H}&<\frac{1}{\frac{p_H}{p_L}-1}\left\{\frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-(\frac{1}{p_L}-1)e(\alpha_L,Q_L)}{1-p_H}\right\}\\&<\frac{1}{\frac{p_H}{p_L}-1}\left\{\frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-[\frac{p_H}{p_L}-1]e(\alpha_L,Q_L)}{1-p_H}\right\}<0\end{aligned}. \tag{B-59}$$

B.3 Proof of Proposition 5

It has been shown, in the solution to [P-B], Case X exists when

$\left[1+\dfrac{e(\alpha_H,Q_H)-e(\alpha_H,Q_L)}{e(\alpha_L,Q_L)}\right]\dfrac{1-p_L}{1-p_H}>\dfrac{a_H}{a_L}>\dfrac{p_H(1-p_L)}{p_L(1-p_H)}$ and

$$C_A < \frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]+\left[\frac{(1-p_H)a_H}{(1-p_L)a_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$$. Properties a and b have been shown in the analysis of Case X. The proofs of Properties a – f are as follows.

In Case X, the employer's expense is

$$EX=(1-p_L)a_L\left\{\frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]+(p_L-p_H)(1-r_A)C_A}{(1-p_H)a_H-(1-p_L)a_L}\right\}+\mu(1-p_H)C_A$$

$$+\mu[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)].$$

(B-60)

Since the employer's expense without the appeals process is

$(\mu+\frac{1}{\frac{p_H}{p_L}-1})[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]$, the appeals process is valuable if and only if

$EX<(\mu+\frac{1}{\frac{p_H}{p_L}-1})[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]$. It can be shown that the appeals process is always valuable and the principal's welfare is increasing in C_A when $r_A=0$ and the opposite is true when $r_A=1$ and C_A is sufficiently large.

Differentiating *EX* with respect to p_L provides

$$\frac{dEX}{dp_L}=-a_L\frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]+(p_L-p_H)(1-r_A)C_A}{(1-p_H)a_H-(1-p_L)a_L}$$

$$-(1-p_L)a_L\frac{[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)]-(1-p_H)(1-r_A)(\frac{a_H}{a_L}-1)C_A}{[(1-p_H)a_H-(1-p_L)a_L]^2}.$$

(B-61)

The first term is $-a_L T_H^A$ which is negative. In addition, the second term is also negative following Equation B-52. Therefore, the principal's expense is decreasing in p_L.

Differentiating *EX* with respect to p_H provides

$$\frac{dEX}{dp_H} = (1-p_L)a_L a_H \frac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]-(1-p_L)(1-r_A)(\frac{a_H-a_L}{a_H})C_A}{[(1-p_H)a_H-(1-p_L)a_L]^2} - \mu C_A . \tag{B-62}$$

Equation B-52 shows $C_A < \dfrac{\left[e(\alpha_H,Q_H)-e(\alpha_H,Q_L)\right]-\left[\dfrac{(1-p_H)a_H}{(1-p_L)a_L}-1\right]e(\alpha_L,Q_L)}{(\frac{a_H}{a_L}-1)(1-p_H)(1-r_A)}$. Since $(1-p_L)(1-r_A)\dfrac{a_H-a_L}{a_H} < (\dfrac{a_H}{a_L}-1)(1-p_H)(1-r_A)$, the sign of the first term in Equation B-62 is positive. It can be shown that $\dfrac{dEX}{dp_H} > 0$ when μC_A is sufficiently small, and $\dfrac{dEX}{dp_H} < 0$ when the opposite is true.

It can be readily shown that $\dfrac{dEX}{d\frac{a_H}{a_L}} < 0$.

APPENDIX C
PROOF OF PROPOSITIONS IN CHAPTER 4

C.1 Proof of Lemma 1

First, for *i=1, 2*, the truth-telling requirement implies that for any pair of values y and y' in $[\underline{x}, \bar{x}]$,

$$T^i(y) - C(y, q^i(y)) \geq T^i(y) - C(y, q^i(y')) \text{ and} \tag{C-1}$$

$$T^i(y') - C(y', q^i(y')) \geq T^i(y) - C(y', q^i(y)) . \tag{C-2}$$

Adding up Equations C-1 and C-2 gives

$$C(y', q^i(y)) - C(y, q^i(y)) \geq C(y', q^i(y')) - C(y, q^i(y')) \tag{C-3}$$

or

$$\int_y^{y'} \int_{q^i(y)}^{q^i(y')} C(m,n) dndm \leq 0 . \tag{C-4}$$

Therefore, if $y' > y$, $q^i(y) \geq q^i(y')$. Incentive compatibility thus implies that $q^i(y)$ is nonincreasing for *i=1, 2*.

Given contact $\{ \{T^i(y), q^i(y)\}$, seller *i*'s utility, for *i = 1, 2*, is

$$U^i(y, y') = \max_{y'} T^j(y') - C(y, q^j(y')) . \tag{C-5}$$

The first-order condition for truth telling, $y' = y$, is

$$U_2^i(y, y') = 0 . \tag{C-6}$$

Equations C-5 and C-6 imply

$$U_2^i(y, y') = -C_y^i(y, q^j(y)) \tag{C-7}$$

Now I show that monotonicity of $q^i(y)$ and the first-order condition C-6 imply that truth telling is globally optimal for seller *i*, where *i* = *1, 2*. Assume that seller *i* strictly prefer announce $y' \neq y$ when his actual cost parameter is y:

$$U^1(y,y') \geq U^2(y,y') \tag{C-8}$$

or

$$\int_y^{y'} U_2^i(y,x)dx > 0 . \tag{C-9}$$

Using Equation C-6, Condition C-9 implies

$$\int_y^{y'} (U_2^i(y,x) - U_2^i(x,x))dx > 0 \tag{C-10}$$

or

$$\int_y^{y'} \int_x^{y} U_{12}^i(r,x)drdx > 0 . \tag{C-11}$$

As $q^i(y)$ is nonincreasing,

$$U_{12}^i(y,y') = -C_y^i(y,q^j(y'))\frac{d}{dy'}q^j(y') \geq 0 . \tag{C-12}$$

If $y' > y, x \geq y$ for all $x \in [y', y]$, and Condition C-11 cannot hold. If $y' < y, x \leq y$ for all $x \in [y', y]$, and again condition C-11 cannot hold. The contradiction shows that $y' = y$ is globally optimal for the seller when monotonicity condition and Equation C-6 hold.

Therefore, seller *i*'s, where *i* = *1, 2*, truthfully announces his cost parameter iff monotonicity condition and Equation C-7 are satisfied.

C.2 Proof of Proposition 2

The first-order conditions of Problem 4-14 are

$$V'(q^1(y)) - C_q(y,q^1(y)) \le 0, \; q^1(y) > 0 \text{ and } (V'(q^1(y)) - C_q(y,q^1(y)))q^1(y) \le 0;$$

(C-13)

and

$$V'(q^2(y)) - C(y,q^2(y)) - \frac{\mu}{1-\mu} C_y(y,q^2(y)) \frac{H^1(y) - H^2(y)}{h^2(y)} \le 0, \; q^2(y) > 0 \text{ and}$$

$$(V'(q^2(y)) - C(y,q^2(y)) - \frac{\mu}{1-\mu} C_y(y,q^2(y)) \frac{H^1(y) - H^2(y)}{h^2(y)})q^2(y) \le 0. \qquad \text{(C-14)}$$

Condition C-13 indicates

$V'(q^1(y) \le C_q(y,q^1(y))(= if \; q^1(y) > 0)$. Similarly, Condition C-14 indicates

$$V'(q^2(y)) \le C(y,q^2(y)) + \frac{\mu}{1-\mu} C_y(y,q^2(y)) \frac{H^1(y) - H^2(y)}{h^2(y)} \quad (= if \; q^2(y) > 0).$$

C.3 Proof of Proposition 5

C.3.1 Property a

Let $W_\lambda^u(\mu)$ and $W_\lambda(\mu)$ represent *B*'s expected surplus when contracting with an uninformed and informed seller given $F_\lambda^2 = \lambda F^1 + (1+\lambda)\widetilde{F}$ where

$$W_\lambda^u(\mu) = \max_{q(z)} \mu \int_Z [V(q(z)) - C(z,q(z))] dF^1(z) + (1-\mu) \int_Z [V(q(z)) - C(z,q(z))] dF_\lambda^2(z)$$

(C-15)

and

$$W_\lambda(\mu) = \max_{q_\mu^1(z), q_\mu^2(z)} \mu \int_Z [V(q_\mu^1(z)) - C(z,q_\mu^1(z))] dF^1(z)$$
$$+ (1-\mu) \int_Z [V(q_\mu^2(z)) - C(z,q_\mu^2(z)) - \frac{\mu}{1-\mu} C_z(z,q_\mu^2(z)) \frac{F^1(z) - F_\lambda^2(z)}{f^2(z)}] dF_\lambda^2(z).$$

(C-16)

Note $W_1^u(\mu) = W_1(\mu)$ so that

$$W_\lambda^u(\mu) - W_\lambda(\mu) = \int_\lambda^1 \frac{d}{d\lambda'}(W_{\lambda'}^u(\mu) - W_{\lambda'}(\mu))d\lambda' . \tag{C-17}$$

Since

$$\begin{aligned} -\frac{d}{d\lambda}(W_\lambda^u(\mu) - W_\lambda(\mu)) = (1-\mu)\int_Z [V(q_\mu^1(z)) - C(z, q_\mu^1(z))](dF^1(z) - d\widetilde{F}(z)) \\ + \mu \int_Z C_z(z, q_\mu^1(z))(F^1(z) - \widetilde{F}(z))dz \\ - (1-\mu)\int_Z [V(q(z)) - C(x, q(z))](dF^1(z) - d\widetilde{F}(z)) \end{aligned}$$

(C-18)

and $q(z) = q_\mu^1(z) = q_\mu^2(z) = q^1(z) = 1$ at $\lambda = 1$,

$$\begin{aligned} -\frac{d}{d\lambda}(W_\lambda^u(\mu) - W_\lambda(\mu))_{|\lambda=1} = (1-\mu)\int_Z [V(q^1(z)) - C(z, q^1(z))](dF^1(z) - d\widetilde{F}(z)) \\ + \mu \int_Z C_z(z, q^1(z))(F^1(z) - \widetilde{F}(z))dz \\ - (1-\mu)\int_Z [V(q^1(z)) - C(x, q^1(z))](dF^1(z) - d\widetilde{F}(z)) \\ = \mu \int_Z C_z(z, q^1(z))(F^1(z) - \widetilde{F}(z))dz > 0 \end{aligned}$$

(C-19)

Since $\frac{d}{d\lambda'}(W_{\lambda'}^u(\mu) - W_{\lambda'}(\mu))$ is continuous and $\frac{d}{d\lambda}(W_\lambda^u(\mu) - W_\lambda(\mu))_{|\lambda=1} < 0$, it follows that

$$\frac{d}{d\lambda}(W_\lambda^u(\mu) - W_\lambda(\mu)) < 0 \tag{C-20}$$

for λ close to 1. This implies there exists a λ_{H} sufficiently close to 1 such that

$$W_{\lambda_H}^u(\mu) - W_{\lambda_H}(\mu) = -\int_{\lambda_H}^1 \frac{d}{d\lambda}(W_{\lambda'}^u(\mu) - W_{\lambda'}(\mu))d\lambda' > 0 \tag{C-21}$$

C.3.2 Property b

First,

$$\begin{aligned}\mu W_\lambda^u(1)-(1-\mu)W_\lambda(0)) &= \mu\int_Z [V(q^1(z))-C(z,q^1(z))]dF^1(z) \\ &\qquad +(1-\mu)\int_Z [V(q_0^2(z))-C(x,q_0^2(z))]dF_\lambda^2(z) \\ &= \mu\int_Z C_z(z,q^1(z))(F^1(z)-\widetilde{F}(z))dz > 0 \\ &> \max_{q(z)} \mu\int_Z [V(q(z))-C(z,q_1^1(z))]dF^1(z) \\ &\qquad +(1-\mu)\int_Z [V(q(z))-C(z,q(z))]dF_\lambda^2(z) \\ &= W_\lambda^u(\mu)\end{aligned} \quad , \tag{C-22}$$

so that $W_\lambda^u(\mu)$ is convex. Further, when the seller is informed about his information structure,

$$W_\lambda(\mu) \geq \mu W_\lambda(1), \tag{C-23}$$

as the buyer can always ensure $\mu W_\lambda(1)$ by offering a contract that only a seller with better information will supply. Therefore I have

$$\begin{aligned}\mu W_0^u(\mu) &< \mu W_0^u(1)-(1-\mu)W_0^u(0)) \\ &= \mu W_0^u(1) \\ &= \mu W_0(1) \\ &= W_0(\mu)\end{aligned} \quad . \tag{C-24}$$

where the first line follows from the convexity of $W_\lambda^u(\mu)$, the second line follows from $W_0^u(0) = W_0^u(0)) = 0$, the third line follows from the fact that $W_\lambda^u(1) = W_\lambda(1)$, and the fourth line follows from Equation C-23. Thus, since $W_\lambda^u(\mu)$ and $W_\lambda(1)$ are continuous in λ, there exists a λ_L sufficiently close to 0 such that $W_\lambda(\mu) > \mu W_\lambda^u(\mu)$ for all $\lambda < \lambda_L$.

LIST OF REFERENCES

Aram, J.D., & Salipante, P.E., Jr. 1981, An Evaluation of Organizational Due Process in the Resoluation of Employee/Employer Conflict. Academy of Management Review 6, 197-204

Baron, D., and Myerson, R. 1982. Regulating a Monopolist with Unknown Costs, Econometrica 50, 911-30.

Bebchuk, L.A. 1984. Litigation and Settlement under Imperfect Information. *Rand Journal of Economics* 15, 404-415.

Blackwell, D. 1951. Comparison of Experiments, in Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability, ed. by J. Newman. Berkeley: University of California Press.

Block, N.J., & Dworkin, G. 1976. *The IQ Controversy: Critical Readings.* New York: Pantheon Books.

Caillaud, B., Guesnerie, R. and Rey, P. 1992. Noisy Observation in Adverse Selection Models. *Review of Economic Studies* 59, 595-615.

Che, Y and Gale, I. 1998. Standard Auctions with Financially Constrained Bidders. Review of Economic Studies 65, 1-22.

Cremer, J. and Khalil, F. 1992. Gathering Information Before Singing a Contract, American Economic Review 82, 566-578.

Cremer, J., Khalil, F., and Rochet, J. 1998a. Strategic Information Gathering Before a Contract Is offered, Journal of Economic Theory 8, 163-200.

Cremer, J., Khalil, F., and Rochet, J. 1998b. Contracts and Productive Information Gathering, Games and Behavior 25, 174-193.

Daughety, A.F. and Reinganum, J.F. 2000. Appealing Judgments. *Rand Journal of Economics* 31, 502-525.

Demougin, D.M. and Garvie, D. A. 1991. Contractual Design with Correlated Information under Limited Liability. *Rand Journal of Economics* 22, 477-489.

Dickens, W. T., Katz, L.F., Lang, K. and Summers, L.H. 1989. Employee Crime and the Monitoring Puzzle. *Journal of Labor Economics* 7, 331-347.

Dye, R.A. 1986. Optimal Monitoring Policies in Agencies, *Rand Journal of Economics* 17, 339-350.

Greenberg, J. 1990. Organizational Justice: Yesterday, Today, and Tomorrow. *Journal of Management* 16, 399-432.

Hadar, J. and Russell, W.R. 1969. Rules for Ordering Uncertain Prospects, American Economic Review 59, 24-34.

Harris, H. and Townsend, R. 1985. Allocation Mechanism, Asymmetric Information, and the Revelation Principle. in G. Feiwel (ed.), Issues in contemporary Microeconomics and Welfare, London: MacMillan, 379-394.

Harris, M. and Raviv, A. 1979. Optimal Incentive Contracts with Imperfect Information, Journal of Economic Theory 20, 231-259.

Jacques. E. 1961. *Equitable Payment.* New York: Wiley.

Kahneman, D., Knetsch, J.L. and Thaler, R. 1986. Fairness as a Constraint on Profit Seeking: Entitlements in the Market. *American Economic Review* 76, 728-741.

Khalil, F. 1997. Auditing without Commitment. *Rand Journal of Economics* 28, 629-640

Laffont, J. and Matoussi, S. M. 1995. Moral Hazard, Financial Constraints, and Sharecropping In El Oulja. Review of Economic Studies 62, 381-400.

Laffont, J. and Robert, J. 1996. Optimal Auction with Financially Constrained Buyers. Economics Letters 52, 181-186.

Laffont, J. and Tirole, J. 1987. Auction Incentive Contracts. Journal of Political Economy 95, 921-937.

Lawarree, J., and Van Audenrode, M.A. 1996. Optimal Contract, Imperfect Output Observation, and Limited Liability. *Journal of Economic Theory* 71, 514-531.

Lewis, T. and Poitevin, M. 1997. Disclosure of Information in Regulatory Proceedings. *Journal of Law, Economics, & Organization* 13, 50-73.

Lewis, T., and Sappington, D.E.M. 1993a. Choosing Worker's Qualifications: No Experience Necessary, International Economic Review 34, 479-502.

Lewis, T., and Sappington, D.E.M. 1993b. Ignorance in Agency Problems, Journal of Economic Theory 17, 169-183.

Lewis, T., and Sappington, D.E.M. 1994. Supplying Information to Facilitate Price Discrimination, International Economic Review 35, 309-327.

Lewis, T., and Sappington, D.E.M. 1997. Information Management in Incentive Problems, Journal of Political Economy 105, 796-821.

Lewis, T. and Sappington, D.E.M. 2000a. Motivating Wealth-Constrained Actors. American Economic Review 90, 944-957.

Lewis, T. and Sappington, D.E.M. 2000b. Contracting with Wealth-Constrained Agents. International Economic Review 41, 743-767.

Mookherjee, D. and Png, I.P.L. 1992. Monitoring vis-à-vis Investigation in Enforcement of Law. *American Economic Review* 82, 556-565.

Moore, B. 1978. *Injustice: The Social Bases of Obedience and Revolt.* White Plains, NY: M.E. Sharpe.

Okun, A.M. 1975. *Equality and Efficiency: The Big Tradeoff.* Washington, DC: The Brooking Institution.

Ottaviani, M. and Prat, A. 2001. The Value of Public Information In Monopoly, Econometrica 69, 1673-1683.

Persico, N. 2000. Information Acquisition in Auctions, Econometrica 68, 135-148.

Picard, P. 1987. On The Design of Incentive Schemes under Moral Hazard and Adverse Selection. *Journal of Public Economics* 33, 305-331.

Reinganum, J.F. and Wilde L.L. 1986. Settlement, Litigation, and the Allocation of Litigation Costs. *Rand Journal of Economics* 17, 557-566.

Riordan M.H. and Sappington, D.E.M. 1987. Awarding Monopoly Franchises. American Economic Review 77, 375-387.

Riordan, M.H. and Sappington, D.E.M. 1988. Optimal Contracts with Public Ex-post Information. *Journal of Economic Theory* 45, 189-199.

Rubinfeld, D.L., and Sappington, D.E.M. 1987. Efficient Awards and Standards of Proof in Judicial Proceedings. *Rand Journal of Economics* 18, 308-315.

Sappington, D.E.M. 1983. Limited Liability Contract between Principal and Agent. *Journal of Economic Theory* 29, 1-21.

Sappington, D.E.M., 1986. Commitment to Regulatory Bureaucracy. *Information Economics and Policy* 2, 243-258.

Shavell, S. 1982a. The Social versus Private Incentive to Bring Suit in a Costly Legal System. *Journal of Legal Studies* 11, 334-340.

Shavell, S. 1982b. Suit, Settlement, and Trial: A Theoretical Analysis under Alternative Methods for the Allocation of Legal Costs. *Journal of Legal Studies* 11, 55-81.

Shavell, S. 1995. The Appeals Process As A Means of Error Correction. *Journal of Legal Studies* 24, 379-426.

Spitzer, M. and Talley, E. 2000. Judicial Auditing. *Journal of Legal Studies* 29, 649-

Townsend, R.M. 1979. Optimal Contracts and Competitive Markets with Costly State Verification. *Journal of Economic Theory* 21, 265-293.

BIOGRAPHICAL SKETCH

Chifeng Dai obtained his B.S. in Material Science and Engineering from Zhejiang University in China in June 1992. Then he obtained his M.A. in Money and Banking from Hunan College of Economics and Finance in China in June 1997. He came to the University of Florida for his Ph.D. in Economics in August 1997. His research interests include Industrial Organization and Regulation, Public Policy, Law and Economics and Applied Econometrics.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as dissertation for the degree of Doctor of Philosophy.

David Sappington, Chair
Lanzillotti-McKethan Eminent Scholar of Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as dissertation for the degree of Doctor of Philosophy.

Chunrong Ai
Associate Professor of Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as dissertation for the degree of Doctor of Philosophy.

Joel S. Demski

Joel S. Demski
Frederick E. Fisher Eminent Scholar of Accounting

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as dissertation for the degree of Doctor of Philosophy.

Jonathan H. Hamilton
Professor of Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as dissertation for the degree of Doctor of Philosophy.

Tracy R. Lewis
Professor of Economics

This Dissertation was submitted to the Graduate Faculty of the Department of Economics in the College of Business Administration and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 2003

Dean, Graduate School